THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XIV DECEMBER, 1901 NUMBER 5

A RUDE ATTEMPT TO DETERMINE THE TOTAL LIGHT OF ALL THE STARS.

By Simon Newcomb

The total amount of light received from all the stars may serve as a control on theories of the structure of the universe, because the amount of light resulting from any theory should agree with the observed amount. It is also a quantity which we must regard as remaining constant from age to age. It seems possible to determine, not only its integral value for the whole sky, but its value separately in each region of the sky. For these reasons it must be considered as among the most important fundamental constants of astrophysics.

A determination, worthy of at least provisional acceptance, offers no difficulty. Making abstraction of such unknown possibilities as the absorption of light in space, or the existence of unknown luminous bodies in the sky, other than stars too small to be separately visible, the total light of all the stars will be simply the total light of the sky, due allowance being made for absorption and reflection in the atmosphere. Such being the case, it would be quite surprising if no attempt to measure the total amount of light received from various regions of the sky

had ever been made; yet I cannot learn of any such determination. This alone can be my apology for publishing so crude a work as the following, which was made only with such apparatus as could readily be got together in a mountain or country resort. Some appliances were kindly supplied by Professor Pickering. I make it known with the hope that it may prove useful in suggesting improved determinations with better appliances, by others.

The problem may be divided into two parts. First, we have the question of the relative brightness of different portions of the sky. This may be expressed by numbers proportional to the brightness of each separate region. We have next the determination, in terms of starlight, of a unit of surface in one or more of these regions. This determination furnishes the unit of measure for the absolute amount of star light received from each unit of the surface, and hence from the whole heavens.

The unit of light which leads to the simplest formulæ for this purpose is that of a star of magnitude 0. As the light received from a square degree of the sky is much smaller than this unit, it will be convenient to introduce a unit one one-hundredth the value of the first. This will be the light of a star of magnitude 5.0.

Either optical or photographic methods may be employed; both are, of course, desirable. As others have much better facilities for making a photographic determination, I have attempted only the optical one.

My original plan was to rest the determination on the minimum amount of light which could be seen by direct vision. I find in the case of my own eye that this is a fairly well defined quantity, being represented by a star of the magnitude 3.8. But the first attempt showed the fovea of my eye to be so insensible to minute lights that no small portion of the sky was visible by direct vision. This plan had therefore to be abandoned and indirect vision used.

The first attempt was made by the sliding tubes of a small spy glass, which could be extended to lengths varying between

30 and 70 centimeters. The ends of the tube were covered with caps having in them openings from 5 to 8 millimeters in diameter. The details of observations with such rough and ready means need scarcely be given. I shall merely state results.

The result of the first attempt was that the minimum portion of sky certainly visible is a circle:

In general average of the region of the galaxy - -	12′ in diameter
In the rest of the sky - - - - - - -	18 in diameter

More careful series of determinations were made by pointing the instrument alternately on the galactic region and in the portion of the sky distant from the galaxy, a certain uniform distance from the galaxy, about 60 degrees, I think, being, in each case, aimed at. The result was:

In the galactic region, diameter - - -	=16′
Distance from galaxy, diameter - -	=18

The determination was then repeated, when vision was had through a dark glass, transmitting 0.5 of the incident light. The patch was taken to look a little fainter. The results were then:

The brighter galactic masses, diameter - -	=14′
The galaxy in general, diameter - - - -	=20
Near galactic poles, diameter - - - - -	=27

Very surprising is the smallness of the difference indicated between the brightness of the galaxy and that of the rest of the sky. The observations were made in as clear and pure air as I have ever seen, and the contrast between the brightness of the galaxy and the seeming darkness of the rest of the sky was very marked. It is to be remembered, also, that the degrees of brightness as observed may differ from each other in a smaller proportion than the surfaces, because the fainter the illumination is, and the larger the surface over which the light is spread, the greater amount of light required to be distinctly visible.

The second method was to make the comparisons by means of small mirrors which could be set up side by side, so as to reflect different regions of the sky. The results of this method were still more surprising. I was unable to detect any difference in the brightness of the sky within the circle of about 25

degrees galactic latitude. No attempt was made to determine the specific brightness of different portions of the galaxy by means of the mirrors, but one of them was placed so as to give a view of the galaxy in general. The general result was that the illumination of the galaxy was only about twice that of the rest of the sky. I venture to give my notes of the first attempt of this kind, as follows:

Two dark glasses were used: I transmitting about two thirds of the light and II one half of it.

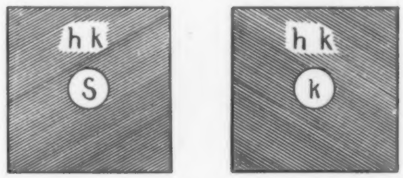
1901, August 16; used mirrors for the first time.
Region A, R. A. $=15^h.5$. Dec. $=55°$.
Region B, near *Lyra*, just west of it.
(1) Without dark glasses, B sensibly brighter than A.
(2) With B seen through glass I - - - B = A.
(3) With B seen through glass II - B less than A.
(4) Galactic region, when seen through glass II, = A.

On subsequent evenings the attempt was repeated under better conditions, with the result already cited, that no difference was perceptible in the illumination beyond about 25 degrees from the galaxy.

I now pass to the second part of the problem, which is the determination of sky light in terms of star magnitude. As it is impossible to concentrate the light of a surface into a small space, we must, in order to compare light of star and sky, spread that of the star out by means of a lens; a concave lens is the best for this purpose. In doing this we meet with the difficulty that the expanded light of the star is superposed upon that of the sky around it. A device was therefore adopted of cutting down the brightness of the expanded image by an absorbing glass to that of the sky. In doing this, however, the eye is likely to be deceived by contrasts. It need hardly be said that only one eye must be used in such comparisons. To avoid error from this source the system finally adopted was this:

By means of a concave lens the light of a star is spread out into an image of known angular diameter *D*. This image is then reduced by being viewed through a dark glass, transmitting

the fraction h of the light. Thus we have in the field of vision a diffused image S of the star and of the sky around it, the whole enfeebled by the fraction h. Alongside of this arrangement let there be a second, consisting of the same or an equally dark glass, having in it an opening of which the apparent angular diameter shall be the same as that of the diffused image of the star. We thus have in the field of view two similar images as shown in the following scheme: K is the sky itself; hK the sky seen through the dark glass, S the diffused image of the star reduced by the fraction h. A star is to be taken, such that the two images shall appear equal.



In the observations made on this system the dark glass was that of a pair of spectacles which, from the best determination I was able to make, transmitted 0.16 of the incident light.

Two concave spectacle lenses were used, one of 6, the other of 8 dioptrics strength. That is, the effective focal distances were one-sixth and one-eighth of a meter.

The following are the notes of the most satisfactory observations I was able to make:

1901, September 16, at home of A. Graham Bell, near Baddeck, Cape Breton Island. Night very fine. Observations commenced at $8^h\ 15^m$, after the setting of the Moon.

LENS OF SIX DIOPTRICS.

α *Pegasi*, reduced to 0.16 = sky near it.

γ *Draconis*, reduced to 0.16, fainter than sky near it.

α *Aquilae*, > Milky Way near it.

α *Ophiuchi* = sky 20 degrees west of it.

α *Cygni*, slightly fainter than general average of the brighter portions of the Milky Way between *Cygnus* and *Aquila*.

γ *Pegasi* < sky southwest of it.

The star of which the brightness seems to correspond most exactly to that of the sky at galactic latitude 40 degrees is α *Pegasi*.

LENS OF EIGHT DIOPTRICS.

α *Cygni* < brightest portion of Milky Way.
α *Aquilae* > brightest portion of Milky Way.
α *Aquilae* = bright agglomerations 20 degrees south.
α *Pegasi* < surrounding sky.

This lens does not work satisfactorily except on stars brighter than magnitude 2.

LENS OF SIX DIOPTRICS AGAIN.

α *Andromedae* slightly < sky south of it.
α *Cygni* = brightest part of Milky Way.
α *Lyrae* much > any part of Milky Way.

Before deriving the results from these observations I shall describe a third class, comprising direct comparisons of the diffused images of stars or groups of stars, superposed on the background of the sky, with the agglomerations of the Milky Way. No dark glass is used in these observations.

At the Moosilauke, 1901, August 16. Concave lens of 2+4 = 6 dioptrics. Looked through both combined.

γ *Lyrae*, + β near maximum, expanded, = mean of neighboring galactic masses seen through the same lens.

Star of magnitude 3.0 = brighter galactic agglomerations near *Aquila*.

Diffused constellation *Delphinus* = average of galactic agglomerations near it.

BADDECK, SEPTEMBER 16. LENS OF EIGHT DIOPTRICS.

β + γ *Lyrae* < average of Milky Way.
γ *Cygni* > brightest agglomerations south of it.
Delphinus as a whole = brightest portions of galaxy.
α *Cygni* much > any part of galaxy.
α + β *Lyrae* = faintest of galactic masses.

I now proceed with the derivation of results from these observations, beginning with those in which an absorbing medium is used to compare the light of that star with that of the sky. In this the diameter of the pupil is to be considered, since the absolute brightness of any object observed with a pencil of rays filling the whole diameter of the pupil varies as the square of that diameter. I have found the effective diameter of the pupil of my eye, that is, the diameter of the external pencil of parallel rays which, after refraction by the cornea, will fill the pupil, to be about 5 millimeters.

Such being the case, and assuming the eye to be accommodated for parallel rays, the image of a star seen through a concave lens of p dioptrics virtual focus in contact with the cornea will be expanded into an image of diameter

$$\frac{57^\circ.2p}{200} = 0^\circ.286p.$$

The most convenient unit of sky surface for our purpose is the area of a circle 1 degree in diameter. Taking as the measure of brightness the amount of light falling on this unit of surface, it follows that if S be the amount of light emitted by a star, the brightness of its expanded image will be

$$b = \frac{S}{(0.286p)^2} .$$

If, instead of being in contact with the cornea, the lens of focal distance $-f$ is at a distance d from it, the angular diameter of the diffused image will be diminished in the ratio $f : f + d$. But the angle which the diameter of the pupil subtends, as seen from the virtual focus, is diminished in the same proportion, as is also the square root of the amount of light which the pupil receives from the star. Hence

The brightness of the diffused image of a star seen through a concave lens by a normal eye is independent of the distance of the lens from the eye.

If the eye is not normal the combination is in effect equivalent to the use with a normal eye of two lenses, one the negative of the lens which, in contact with the cornea, would correct the abnormal refraction; the other the actual lens used.

In the present case the eye has a mean abnormal refraction of about $+0.5$; it will serve our present purpose if we allow for this by diminishing the negative power of the lenses by this amount, thus assigning to p the values 5.5 and 7.5 for the two lenses. We thus have, for the brightness of star images seen through the lenses:

$$\text{Lens of } 6D:\ b = \frac{S}{2.47} .$$

$$\text{Lens of } 8D:\ b = \frac{S}{4.60} .$$

When a star is viewed in the way in question its light is superposed upon that of the sky around it. Let us put

$y =$ brightness of sky around the star.

The brightness of the image will then be increased by y. This image being viewed through an absorbing-glass of power h, the brightness of the image as seen will be

$$b = h\left(\frac{S}{2.47} + y\right) \text{ or } h\left(\frac{S}{4.60} + y\right).$$

Putting, as already stated, $h = 0.16$, we have for the brightness of the images

$$b = 0.065S + 0.16y \quad . \quad . \quad . \quad (6D)$$
$$\text{or} \quad b = 0.035S + 0.16y \quad . \quad . \quad . \quad (8D).$$

To obtain the results these expressions are to be equated to y itself, stars having been taken to nearly satisfy this equation.

As I was not able to detect any well-marked difference of brightness between different portions of the non-galactic sky, I shall use but one value of y. Taking the light of a fifth magnitude star as unity we have, for a star of magnitude m

$$S = 10^{2.0 - 0.4m}$$
$$\text{or} \quad \log S = 2.0 - 0.4m.$$

Taking the magnitudes of the stars from the Harvard photometry we have the following equations from the observations :

LENS OF SIX DIOPTRICS.

α *Pegasi*,	$m = 2.5$	$0.65 + 0.16y = y.$
γ *Draconis*,	$m = 2.5$	$0.65 + 0.16y < y.$
α *Ophiuchi*,	$m = 2.2$	$0.86 + 0.16y = y.$
γ *Pegasi*,	$m = 3.0$	$0.41 + 0.16y < y.$
α *Andromedae*,	$m = 2.1$	$0.94 + 0.16y < y.$

The best result we can get from these rather discordant equations is $y = 0.90$.

That is to say, a circle of the non-galactic sky 1 degree in diameter gives 0.90 of the light of a star of magnitude 5.0.

A more precise determination of the brightness of the galactic agglomerations is obtained by the third method. But

when a single star is used the eye is liable to underestimate the brightness, by substituting for it a certain fraction of the total amount of light, that is to say, if n be a considerable number, say 20 $\pm$, a light of $20s$ spread over an area of $20a$ will be estimated as brighter than one of s spread over the area a. I first noticed this at Baddeck.

I cannot identify the star of supposed magnitude 3 which, expanded into an area of about 2.5 degrees, looked equal to the galaxy, and regard the result as too great, for the reason just stated. For the galaxy let us put

g_2, brightness of mean agglomerations,
g_3, brightness of brighter agglomerations,

these values expressing amounts of light in addition to those received from the background of the sky.

The combined light of β and γ *Lyrae* I consider to have been diffused over an area, subjectively considered, of 7 degrees, the whole being expanded into an ill-defined, diffused mass, instead of a pair of circular disks, which would have been the actual form. For the two stars we have $S = 9.6$, and therefore $g_2 = 1.4$.

The most definite result seems to be that given by the constellation *Delphinus*, which, with the lens of eight dioptrics, was expanded into a mass of brightness g_3. The area as it appeared may be estimated at 14 circular degrees. The total light of all its most condensed collection of lucid stars is 13. It would follow from the observation of *Delphinus* that the brightest regions of the galaxy are 0.93 brighter than the background of the sky in *Delphinus*. This background seemed to me but little in excess of that of the non-galactic sky. Calling its brightness y', we should have $g_3 = 0.93 + y' - y$.

Assuming the background to be 50 per cent brighter than that of the non-galactic sky we have, from $y = 0.90$, $g_3 = 1.38$.

That is to say:

The total mean brightness of the brighter agglomerations of the Milky Way, including the light of the sky, is 2.28. Subtracting 0.90 for the light of the non-galactic sky, we find that

the total light per unit of surface received from these agglomerations is 1.38, or about 50 per cent. more than that from an equal area of the non-galactic sky.

Let us compare this conclusion with that from observations of the first class, in which the visibility of the sky through a small opening was examined. There is one uncertain element in the interpretation of the latter, the effect of the size of a surface on its visibility under a faint illumination. If we have a definite quantity of light it will be more and more distinctly visible as it is more condensed. In other words, if we suppose a series of illuminated circular disks subtending various angles, the amount of light necessary to make one of them visible will be greater, the greater the surface. But this amount will not increase in proportion to the surface because the visibility of every portion is reënforced by the illumination of the surrounding portions. I am not aware that any determination has ever been made of the law governing this case. Our result, therefore, must be in part hypothetical. The most definite result seems to be that the minimum portion of the sky distinctly visible near the pole of the galaxy has about double the diameter of the least visible portion in the brighter galactic agglomerations. The former has, therefore, four times the surface of the latter. If the absolute amount of light is the same we should conclude from this that the agglomerations were four times as bright as the background of the sky near the galactic pole, so that

$$g_3 = 3y.$$

All we can say of this result is that it is too large, but, apart from its considerable probable error, not much too great. If, as the mean result, we suppose the amount of light required to be visible to vary inversely as the diameter we should have

$$g_3 = y$$

a result in agreement with that derived from the observations of the third class.

One conclusion from these observations may seem to require

explanation. From the value of y already found the amount of light received from a patch of non-galactic sky $12'$ in diameter is 0.036 of that of a star of the fifth magnitude, which is somewhat less than the light of a star of the eighth magnitude. The conclusion that a star of the eighth magnitude is not below the limit of visibility on a dark ground requires verification, but may be accepted on the ground that the ordinary invisibility of stars below the sixth magnitude arises from the light of the sky on which the star is projected. The latter fact may be easily verified by looking at the sky through a pair of dark-glass spectacles. With those already mentioned, which reduce the brightness of a star by about two magnitudes, I noticed that, although my eye is now far from being of the best, 51 H *Cephei* was faintly visible, while δ *Ursae Minoris* was very distinct. The magnitudes of these stars being 5.2 and 4.2 it seems that, against the background of the sky reduced to one-sixth of its normal brightness, a star of 7.2m is visible to my eye.

Allowing as wide a range of uncertainty as I think we should attribute to these observations, the general conclusions may be summed up as follows:

Taking as the unit of surface that of a circle 1 degree in diameter, and measuring its brightness by the amount of light received from it, in terms of the light of a star of magnitude 5.0, as unity, the brightness of the sky near the galactic pole is 0.9 with a mean error ± 0.2.

In the brighter agglomerations of the galaxy, measuring the brightness in each case by its mean value in a circle not less than 5 degrees in diameter, its brightness is equal to that near the galactic pole, plus a quantity which probably lies between 1.0 and 1.5.

These results are at variance with those which I had supposed to be derivable from existing photometric and statistical data. We suppose the light of the background of the sky to be due wholly to the telescopic stars; and the fact is that the amount of light which results from these observations is no greater, but perhaps less than we should expect from the totality of such stars. Now, it

is well known that the thickness of the stars to magnitude 9.0 steadily increases from the galactic pole toward the galaxy itself. According to Seeliger's count the number of these stars at 30 degrees galactic latitude is nearly double that at the galactic pole. Moreover, the condensation continually increases as we include fainter stars. From the ordinary ratio of the number of stars of each magnitude to that of the stars one magnitude fainter, it is readily shown that the total amount of light received from the stars of each successive order of magnitude should continually increase as we include fainter stars. The gauges of Herschel show ten and even twenty times as many stars per square degree in the galactic agglomerations as near the galactic pole. We should therefore suppose that the sky at 30 degrees galactic latitude ought to be more than twice as bright, and in the agglomerations, ten times as bright as at the pole. Moreover, the impression one gets by simply looking at the galaxy is certainly that of being several times brighter than the background of the sky.

One explanation of the paradoxical character of my result will at once present itself for consideration. Of the light which reaches us from a heavenly body, not only is a portion lost by the absorption of our atmosphere, but a certain fraction is also reflected from the air. It follows therefore that the light received from any region of the sky is composed of two parts, the one reaching us directly from the telescopic stars, the other reflected from all the stars above the horizon. I do not know whether any accurate determination of the proportion of light thus reflected has ever been made. I essayed, in a way even more rude than that of the rest of the observations, to determine it at the Moosilauke. The method used was to lay a sheet of white paper on the ground where it was exposed to the full light of a large portion of the sky, and also to that of the direct rays of the Sun. Direct sunlight was cut off from one portion by an opaque obstacle while the other portion was viewed through an absorbing glass. I found that, using the glass already described of absorption 0.84, the portion of the paper illuminated by the Sun,

when seen through this glass, generally looked brighter than that illuminated only by skylight, but did not seem twice as bright. The principal difficulty in making a satisfactory estimate arises from the blue color of the light of the sky, which I found it difficult to compare with the comparatively brown light of the Sun. My general conclusion was that the amount of reflected light was probably one tenth that received from the Sun, perhaps a little more.

Assuming that one nth of the light coming from a heavenly body is reflected by the atmosphere, the total amount of light received from any small region of the sky is that coming from the telescopic stars in that region, diminished by atmospheric absorption and reflection, and increased by one nth of the amount of light we should receive from that region, were the stars equally scattered over the heavens. Putting $n = 10$, the effect would be slight, and altogether, it does not seem that any admissible use of these numbers would lead to a material modification of my results.

The question will naturally arise whether, possibly, the sky may not have been illuminated by extraneous light during my observations. In my opinion there was no appreciable amount of light from any terrestrial source. At neither station were there electric lights within many miles. The only lights within a radius of five or six miles were a few gas lights in neighboring towns which, I believe, could not have had any observable effect, and some lanterns of which the effect was insignificant.

Care was taken to observe only when the Moon was below the horizon. The planets *Jupiter* and *Saturn* were in the sky, but it is clear that their light could not have affected the result.

On the whole it seems either that my observations are wholly at fault—erroneous by an amount which I should find it difficult to account for, or we must materially modify our conclusions from the combination of star gauges with the existing photometric estimates of star light. One step in this latter direction I have made in a recent number of the *Astronomical Journal.* On discussing the magnitudes of the Cordoba *Durchmusterung*, when

reduced to the Harvard photometric standard, I reach the surprising conclusion that, from the data there presented, there was no increase in the total amount of light received from all the stars of each order of magnitude, as had always been inferred from previous counts. If a similar conclusion is drawn from the study of statistics pertaining to the northern heavens the way for a reconciliation may be open. Considering only the present rude observations, their result is about this:

The total light of all the stars is about equal to that of 600 stars of magnitude 0, with a probable error of one fourth its whole amount. There is, however, more room for a positive than for a negative correction; it is not at all unlikely that the number may be greater than 800.

The large range of uncertainty will seem less striking if we reflect that it only amounts to $\pm 0.3^m$ or $\pm 0.4^m$ where expressed in star-magnitude.

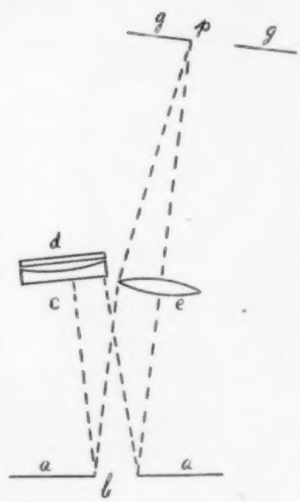
I regard the present paper useful mainly in suggesting a careful investigation by others with better instrumental means than the rude ones at my disposal. The determinations should be made by photography as well as optical; indeed, were it not that the photographic plate measures mainly the blue light, the optical method would be scarcely worth employing. As a matter of fact, however, it affords a nearer approximation to the total energy than does the photographic effect. I therefore make the following suggestions as to the method of conducting the experiments.

The brightness of various portions of the sky may be determined not only by their juxtaposition through reflection in mirrors, but by comparing various portions of the sky with a faintly illuminated canopy, care being taken to use a light of the same color as that of the sky. Comparative estimates could, in this way, be made with great precision, but I fear it would not be possible to fix a value of the albedo of the canopy with such precision that the method could be used for absolute measures.

The first method, in which the sky is viewed through a small

opening, is subject to a large probable error in the individual observations, but by repeating them, pointing in rotation on different regions of the sky, I think that constant error could be avoided. This seems to be the method which is open to least doubt.

In the adoption of the second method the appliances used should be attached to a telescope with an equatorial mounting, which I was unable readily to command at either station.



The accompanying figure embodies my idea of the best form of apparatus for the purpose. The dimensions which I give are only provisional, serving as a preliminary guide to the observer.

a a is a metallic plate, with a hole *b*, acting as an artificial pupil of constant diameter. I did not use this in my observations. The diameter of *b* should be less than that of the actual pupil, perhaps 4 mm. *c* is a concave lens of focal length −16cm.

d is an absorbing glass in contact with the lens.

e is a convex lens, of which the power may be about the same as that of *c*, taken positively.

g g is a dark glass of the same strength as *d*, having through it an opening *p*, placed in the focus of *e*. A photographic film may be used, if the cutting of a hole in the glass is impracticable, but the hole is to be preferred.

The distance of *g* from *e* should be such that the angular diameter of the hole *p*, as seen by an eye behind *a a*, should be equal to that of the diffused image of a star seen through the hole *b* and the lens *c*.

The entire apparatus should be attached to a bed-plate or rod mounted on axes so as to admit of being rapidly pointed to various parts of the sky. Care must be taken to so adjust

the lenses *c* and *e* and the plate *g p g* that *b* shall be filled by each pencil of light, especially that *g* does not cut off any light from the star.

The whole combination should admit of easy reversal on a longitudinal axis, so that the images of the star and of *p* on the retina may be readily interchanged.

SPECTRAL PHENOMENA CONNECTED WITH THE COOLING OF VERY HOT STARS.

By H. Kayser.

In the spectra of several stars, some of the hydrogen lines appear bright and others dark. Campbell[1] has thoroughly investigated this appearance and has found that the brighter lines always correspond to greater wave-lengths, and that the brightness decreases with decreasing wave-lengths while the darkness of the dark lines increases in the same order. Campbell considers that these stars represent the transition between Vogel's Ia class and Ic class. He believes it possible that this transition takes place in such a way that all the bright lines do not become dark at the same time, but that the change occurs by degrees. He cannot, however, give any explanation of this phenomenon.

Scheiner[2] opposes this opinion and writes categorically as follows: "The statement that in any spectrum, bright and dark lines belonging to the same substance can at the same time occur, so contradicts the simplest consequences of Kirchhoff's law that it must be dismissed as impossible." This expression of opinion shows that Scheiner is not acquainted with the numerous experiments which have been made on the reversal of spectral lines, since all these experiments have uniformly shown that only single lines of a spectrum can be reversed, whether it is a question of self-reversal or one of reversal on a continuous background. Also this appearance, far from contradicting Kirchhoff's law, is in reality in most perfect harmony with it, as may easily be seen from an elementary consideration of the law.

If e be the coefficient of emission of a radiating body 1, for a certain wave-length, and E that of a second absorbing body

[1] W. W. Campbell, Astrophysical Journal, 2, 177, 1895.

[2] J. Scheiner, *Astron. Nachr.*, No. 3733, p. 195, 1901.

2, whose coefficient of absorption is A, then according to Kirchhoff

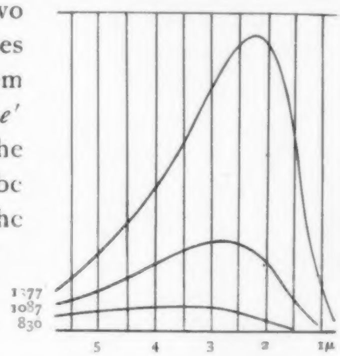
$$E = e'A,$$

where e' represents the coefficient of emission of a perfectly black body at the same temperature as the absorbing body 2. As is well known, the absorbing body 2 must be colder than the body 1 in order to render reversal possible, *i. e.*, $e' < e$. Whilst the body 1 is emitting the amount e, the fraction eA will be absorbed by the body 2, which, however, adds to the total radiation the quantity $E = e'A$, so that from 1 and 2 together we get $e-(e-e')A$.

If a line of a spectrum is visibly reversed then this intensity must obviously be smaller than e; so that the reversal will be more distinct the greater $(e-e')A$ is, as compared with e: that is, the greater the difference of temperature between 1 and 2 and the coefficient of absorption of 2 are. Therefore for a given difference of temperature all the lines will not be reversed, but only those for which $(e-e')A$ is large enough. Those lines for which A, and therefore E, is very small will not become visible as dark lines: that is, in general, only the strongest lines will exhibit reversal.

In order to investigate what becomes of the non-reversed lines we must decide whether the body 1 gives a continuous spectrum or whether it is the same gas as 2. In the first case the bright lines disappear in the scarcely brighter background, as Liveing and Dewar have several times observed. In the second case the lines remain bright, so that the spectrum of the gas is a mixture of bright and dark lines. So much for Scheiner's sweeping assertion. Returning to the original question, the conclusion arrived at above that first of all the brightest lines are reversed, appears to be inconsistent, since the longest wave-lengths of the hydrogen spectrum are the brightest, the intensity decreasing from the fundamental to the shorter waves of the series, and accordingly one would expect to find the longer wave-lengths reversed and the shorter ones bright. I think, however, that this apparent contradiction can be explained.

In the last few years we have become more intimately acquainted with the emission curves of a perfectly black body. In the accompanying diagram the curves corresponding to temperatures of 836°, 1087° and 1377° as observed by Lummer and Pringsheim are given, and it seems to me they afford a solution to our problem. Suppose the two upper curves to be those for our bodies 1 and 2. We can read off from them for any wave-length the quantity $e-e'$ as the difference of the ordinates at the wave-length in question. It will be seen at once from the form of the curves that the ratio of $e-e'$ to e for long wave-lengths is comparatively small and increases gradually, becoming relatively large when the maximum of the lower curve is passed. Beyond a certain wave-length, the value of e' becomes practically zero, so that the ratio $e-e'$ to e is approximately unity. If therefore A were identical for all spectral lines we should get the result that $e-(e-e')A$ differs more from e and therefore the reversal becomes stronger as we proceed to smaller wave-lengths and that the reversal becomes particularly strong when we pass the wave-length of maximum energy for the absorbing body. But in a series the value of A decieases in the same proportion, thereby weakening the effect of the variation of $e-e'$ without however necessarily annulling it. This would then explain well why the short wave-lengths are most easily reversed.



The phenomenon is, by the way, not confined to stellar spectra, for as early as 1871 Cornu drew attention to the same appearance in arc spectra and anyone who has photographed arc spectra can confirm it.

Should my explanation be correct some interesting results would follow. From the position of that line in the spectrum where the darkness of the reversed lines begins rapidly to increase, some idea of the temperature of the absorbing enclosure

could be obtained, the temperature being higher the greater the number of bright lines. I admit that the phenomenon becomes more complicated by Campbell's beautiful observation that the intensity of the hydrogen lines does not necessarily decrease from the first member but may actually increase for the first few members of the series, which seems to me to indicate a very high temperature.

In any case I consider that the existence of bright lines proves that the temperature is very high and the maximum of the e' curve must lie in the visible part of the spectrum. On the other hand, the fact that we have a mixture of dark and bright lines proves that the nucleus does not radiate like a solid body, that is, that its density is very small compared with other stars, which is also an indication of a high temperature.

If then a star, in which the whole hydrogen series is bright, gradually cools down, the series will by degrees become reversed, beginning at the lowest members and last of all $H\alpha$. Campbell was therefore perfectly correct in his supposition.

The only hypothetical part of this explanation is that we compare the emission from a gas with that of a solid body, *i. e.* we assume the intensities of the lines to be approximately the the same as those which a perfectly black body would have in the same part of the spectrum. I believe that this may be safely assumed in the case of a line series and the above mentioned observations of Campbell's are in favor of it. At any rate, it must be correct for the case of an infinitely thick layer of gas.

BONN, October 1901.

ON DRIFT IN LONGITUDE OF GROUPS OF FACULÆ ON THE SUN'S SURFACE.

By A. L. Cortie.

From a discussion of 108 faculæ on photographs taken in the year 1884, at Potsdam, Wilsing found no indications of any drift in longitude with decrease in latitude, such as was established by Carrington for Sun-spots. Stratonoff, however, in his memoir "Sur le mouvement des facules solaires," determined that in the case of faculæ connected with spots, they followed the same laws of rotation as the spots, although in general the faculæ had a greater velocity of rotation. Moreover, faculæ in different latitudes had different velocities, but the law seemed to be more complicated than in the case of spots. In the discussion of the observations, 234 plates were chosen for the years 1891–1894. On these plates 2245 positions were measured in 1062 separate faculæ. The great majority of them were only observed during one day, 103 were observed for two days, and 5 during three days.

Previously, however, to the appearance of Stratonoff's paper, Father Sidgreaves, in his "Notes on Solar Observations at Stonyhurst College Observatory,"[1] had treated of selected groups of faculæ observed during the year 1889, and which had been followed as entire groups in their transits across the Sun for considerable periods of time. He showed that the faculæ under this aspect followed the same law of drift in longitude as the spots. In his paper only the results of the discussion were given, and the detailed presentment of the observations on which the conclusions were founded was reserved for a future occasion.

The present paper is therefore supplementary to that of Father Sidgreaves, and, while traversing the same ground, gives

[1] *Monthly Notices R. A. S.*, Vol. LV, No. 1, November 1894.

a more detailed, and at the same time an independent treatment of the observations. Moreover, it is illustrated by diagrams of the several groups of faculæ studied, which serve as a most convincing and striking evidence of the reality of the drift. The question proposed, therefore, is whether groups of faculæ as a whole, and not separate determined points in any one group, give evidence of the same or a similar law of decrease of angular velocity with latitude, as the spot groups do.

As was pointed out in the former paper, the first difficulty in treating groups of faculæ is that of identification, and the following of any specified group in its passage across the solar disk, especially as it can be observed only when near the limbs of the Sun. On the Stonyhurst drawings the average distance from the limbs at which faculæ are drawn is half the radius of the solar image. In years of maximum activity, when the faculæ are so numerous that they practically form luminous belts all round the Sun, it is well-nigh impossible to distinguish the different outbursts one from another in all the stages of their life history. The difficulty, however, is not so great in the years of minimum, when the outbursts are less numerous and more separated in time. If, too, those groups of faculæ be selected for study which are connected with spots, the difficulty of identification is considerably diminished. Moreover, the law of the formation and growth of faculæ accompanying spots is a further guide to identification, the various phases in their growth being generally as follows:

First a few intensely bright flecks of faculæ are seen, which after a day or two are followed by the appearance of small spots. In the earlier stages of the life-history of the spots, the faculæ cling closely round the spot-groups, growing with the spots, and being very bright. When, however, the spot-group is nearing extinction, the faculæ attain their fullest development, and appear in their most typical branching forms. The average life of a group of faculæ is from four to five times that of the spot-group which it accompanies. As the faculæ

groups grow older they become less compact and bright, and spreading over wider areas gradually disappear.

In the present instance the year of minimum solar activity 1889 was selected for study. Of 121 different groups of faculæ drawn at Stonyhurst during that year, 25 were connected with spots. Of these 25 again, 13 have been closely followed and watched during a prolonged period, ranging from 120 to 19 days. These are set down in the following list:

Number	First observed			Recorded duration in days	Mean Heliographic		Relative magnitude
					Longitude	Latitude	
1	1888	Dec.	11	81	354°	− 9°	2
2	1889	Feb.	21	38	116	− 8	3
3		March	5	27	320	− 8	2
4		March	13	100	319	+ 7	2
5		May	5	110	217	− 3	5
6		May	30	109	33	− 8	7
7		June	23	29	64	− 8	1
8		July	12	35	89	− 8	2
9		July	26	28	339	−26	1
10		July	27	27	203	− 2	1
11		July	29	19	296	+ 5	1
12		July	31	120	152	−24	5
13		Aug.	10	23	84	− 9	2

These thirteen cases were carefully selected after inspection of the seventeen sheets, one to each solar rotation, which cover the period 1888, September 24, to 1890, January 1. On these, both the spots and the faculæ have been set down in their proper positions, the heliographic co-ordinates of each member of every group having been determined from the original drawings by means of a set of very accurate orthographic projections of the parallels of longitude and latitude of the solar disk for every degree slant of its polar axis. A full description and discussion of the accuracy of these projections is given in the *Monthly Notices R. A. S.*, Vol LVII, No. 3, January 1897. This laborious work, as well as the original drawings, is due to Mr. William McKeon.

In the study of the drift of the selected groups, the method

of Carrington in his *Observations of the Solar Spots* has been adhered to. The center of each group of faculæ chosen was that which, after due inspection of the diagrams, was judged to give the most truthful result for the diurnal motion. One specimen of the method followed in all cases will suffice:

GROUP 12.

Rotation	At days	Long.	Lat.	Means d.	Means Long.	Means Lat.
I.	211.48	155°	—22°	216.99	158°	—22.5°
	213.40	156	—22			
	221.53	161	—23			
II.	240.63	156	—24	244.78	155	—24.0
	248.46	156	—23			
	249.38	152	—25			
III.	267.36	151	—25	271.90	150	—25.5
	276.44	149	—26			
	294.39	148	—25	294.94	145	—25.5
	295.49	142	—26			

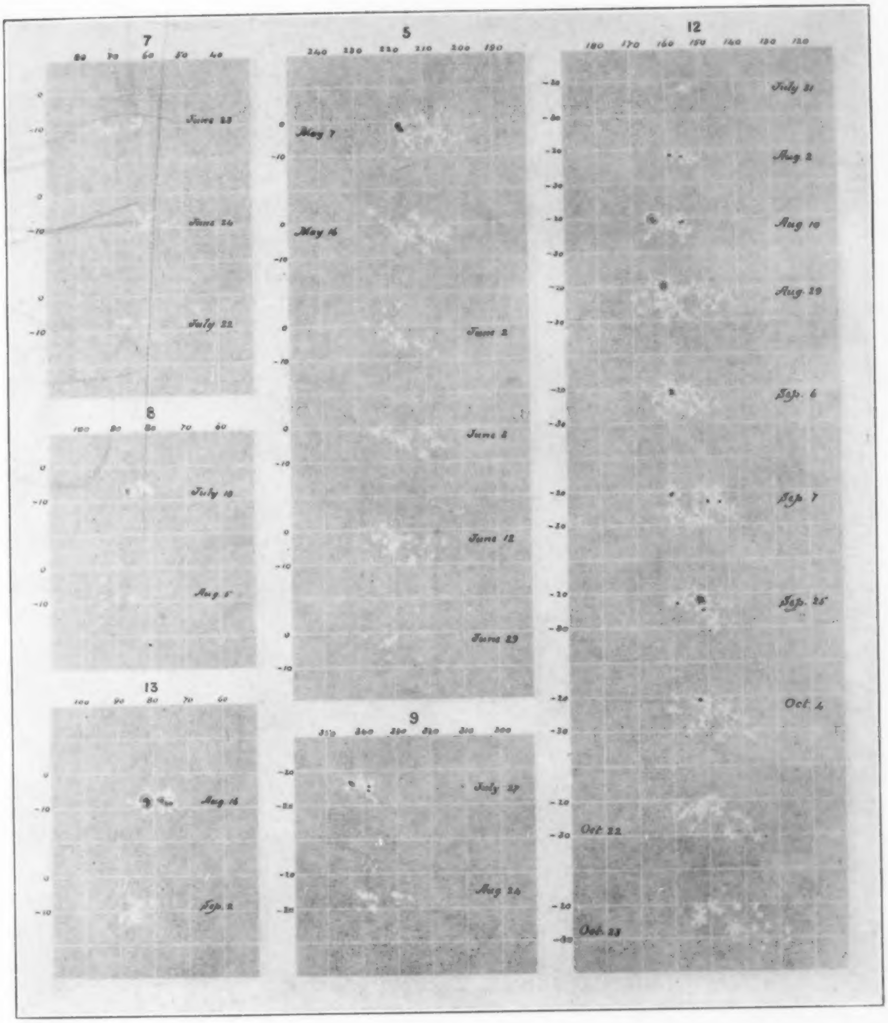
Hence

At days	Long.	Lat.	Diurnal motions
216.99	158°	—22.5°	— 7′ and +3′
244.78	155	—24.0	—11 and +3
271.90	150	—25.5	—13 and 0
294.94	145	—25.5	

mean diurnal motion —10′ and +2′ for latitude —24°.

The results for all the groups similarly studied are collected in the following table. The signs prefixed to the concluded diurnal motions are such that + in longitude indicates rotation faster than 14° 11′ for each solar day, Carrington's adopted mean, and + in latitude, motion towards either pole. As in Carrington's results for the spot-groups, the figures are given to the nearest whole number.

PLATE XXI.



DRIFT OF FACULÆ IN LONGITUDE.

Number	Mean latitude	Mean Diurnal Motion	
		Longitude	Latitude
1	− 9°	+ 8′	+1′
2	− 8	+21	+0
3	− 8	+38	+2
4	+ 7	+15	+0
5	− 3	+11	+2
6	− 8	+14	+5
7	− 9	+ 6	−2
8	− 8	+31	+7
9	−26	−15	+2
10	− 2	+19	+2
11	+ 5	+ 7	+0
12	−24	−10	+2
13	− 9	+18	+4

Collecting these results for the different latitudes, and comparing them with Carrington's results for spots, we have:

Latitude	Number of groups	Mean Daily Angular Motion	
		Faculæ groups (Stonyhurst)	Spots approximate (Carrington)
+ 7°	1	14°.5	14°.3
+ 5	1	14.3	14.7
− 2	1	14.5	13.9
− 3	1	14.4	14.2
− 8	4	14.8	14.3
− 9	3	14.4	14.4
−24	1	14.0	13.8
−26	1	13.9	13.7

The rotation period 14°.2 per solar day for the spots applies to the latitude 14° north and south in Carrington's final results. For higher latitudes the rotation period is slower and for lower latitudes faster. The above table shows that at least in the cases studied the faculæ too follow the same law of drift, and corroborates for groups followed during long periods of time in their entirety, what Stratonoff has established for separate points of faculæ followed at most for three days.

An inspection too of the accompanying diagrams in which

these carefully selected cases are set down in their true positions, all doubtful cases having been rigidly excluded, shows the drift established by the tables in a most satisfactory manner. In some cases an apparent lagging of the faculæ behind the spot will be noticed. This, however, is due to the disappearance of the following members of the spot-groups. The faculæ have remained in the positions they occupied relatively to the vanished members of the spot-groups. Seeing that the faculæ live so much longer than the spots, and, after the disappearance of the spots, are not disturbed by the action of spot formation, were the difficulty of identification overcome it would seem possible to establish a more uniform law of drift from observations of them, than even from the spots. The table also seems to show, in the limited number of cases discussed, a faster rate of daily angular motion for the faculæ than for the spots.

Stonyhurst College Observatory,
July 22, 1901.

SOME NEW PECULIARITIES IN THE STRUCTURE OF THE CYANOGEN BANDS.

By A. S. King.

In this paper a short account is given of the writer's investigation of the arc spectrum of carbon, special notice being taken of a banded structure in the ultra-violet region, which appears to have been overlooked by previous observers; at least these bands have not been measured and considered in relation to the other bands of the carbon spectrum.

Photographs of the spectrum were taken by means of a Rowland concave grating of fifteen feet radius, ruled with 15,000 lines to the inch. The well-known bands in the violet and ultra-violet with heads at 3883 and 3590 affect the photographic plate so strongly that an exposure of about ten seconds is sufficient for good definition of these bands. It is only on plates which have been exposed for a much longer time (at least one minute), so long that the bands just referred to are much overexposed, that we can see another series above the 3590 band. This series begins at 3465 and reaches almost to the copper line at 3274. It consists of eight dense portions which have the appearance of heads of bands with their sharp edges toward the region of shorter wave-length and shading off toward the red. The first five beginning at 3465 are the most distinct. Another series, much fainter, but of the same general character, appears below the copper line at 3247 (see Plate XXII, Fig. 1).

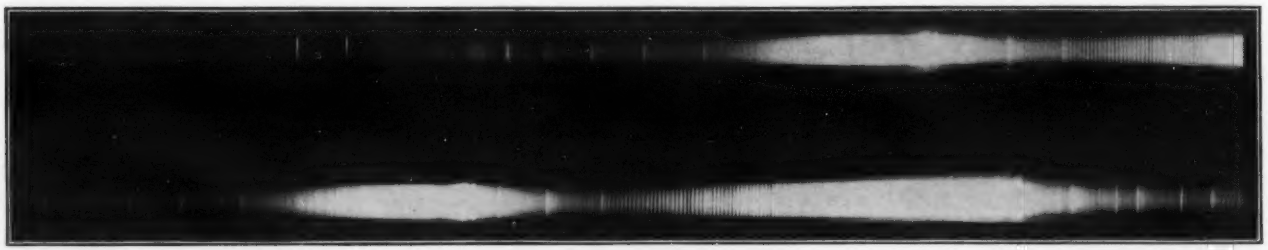
The wave-lengths of these two groups of apparent heads were computed by measuring their distances from the copper lines at 3247.65 and 3274.06 and taking these wave-lengths as a basis. In this way the following values were obtained:

Group I	Group II
3203.84	3465.69
3180.58	3433.17
3160.32	3405.04
3143.06	3380.58
3128.00	3360.27
	3340.64
	3322.40
	3296.48

Two questions in regard to these series must now be considered: (1) Are they really a part of the carbon spectrum or are they due to foreign matter? (2) May they not be caused by lines belonging to different heads of the known bands occurring close together or superposed at these points? We have the following evidence bearing on the first question: (1) The lines in this region have the same appearance as those in other parts of the carbon arc spectrum, and show a decided contrast to the sharp definition of the metallic lines due to impurities in the carbons. (2) With a long arc, the metallic radiation is strongest near one end of the arc, and the lines appear more intense at one side of the plate, while the series under discussion continue uniformly across the plate, as do the regular carbon bands. (3) Some of the plates were taken with very pure carbons prepared by a process to be described later, which gave no metallic spectra except traces of copper and calcium. (4) When the arc was surrounded by various gases, changing the intensity of some of the bands, the effect on these two series of bands was the same as on the two series with heads at 3590 and 3883. The evidence before us thus leads to the conclusion that the two series beginning at 3203 and 3465 belong to the same spectrum as the cyanogen bands at 3590 and 3883.

Taking up the second question, the idea that the banded appearance in the ultra-violet might be caused by an approach or superposition of lines belonging to different parts of the known bands was held by the writer at first, but it is not supported by the appearance of the banded structure. If it is caused by superposition of lines belonging to different heads, these heads would probably be those of the 3590 band. The new bands are at a considerable distance from the band at 3590. If, then, the successive lines of each of the heads belonging to the 3590 band become more and more separated as the distance from the head increases, as we should expect them to do, it is unlikely that there would be a sufficient number of lines in a short space to produce so dense an appearance, even if several lines belonging to different heads came close together in places.

PLATE XXII.



SPECTRUM OF CYANOGEN.

Besides, the structure in this region is very different from that in other parts of the spectrum where there are evidently superpositions of lines belonging to different heads.

It thus appears that the gradual separation of the lines as they recede from the head does not explain the occurrence of the dense portions at a distance from the head. Let us now see if the law of spectral series, so far as it has been worked out, affords any explanation of the observed structure. An article by Thiele in this JOURNAL, **6**, 65, 1897, offers a suggestion along this line by stating a mathematical condition which seems to be fulfilled in the structure of the cyanogen bands.

In this article, Thiele considers himself justified in asserting that an expression which shall give the wave-length of any line of a series as a function of the series-number n of the line must have the form $\lambda = f\left[(n+c)^2\right]$, where c is a constant which he calls the "phase" of the series. Taking this equation as a basis, he notes that if n be given successively all real integral values, λ will have a maximum and a minimum value at $\lambda_0 = f(0)$ and $\lambda_\infty = f(\infty)$ respectively. The physical meaning to be attached to these values is that in the neighborhood of λ_0 a finite number of lines are united in an ordinary head, while near λ_∞ an infinite number of lines are crowded into a finite space, that is, the region close to the value λ_∞. We should then expect a strong condensation near λ_∞, which Thiele calls the "tail" of the series. He then works out relations involving λ_∞, which, however, he does not apply to band spectra, and some of the constants used, notably n, the series number of a selected line, are very hard to determine in the case of band spectra. In Thiele's later article in this JOURNAL, **8**, 1, 1898, on series in the third carbon band, he does not consider the value λ_∞, and makes no attempt to locate the tail of this or of other bands. His object in this article is to find a formula giving the wave-length of any line in terms of its series number and constants.

It thus appears, if Thiele's hypothesis is correct, that each series should have a definite ending; that there should be a tail

corresponding to each head in a band spectrum. The appearance and location of the band-like structure in the ultra-violet at once suggests the idea that these apparent heads are really the tails of the cyanogen bands at 3883 and 3590; and I wish besides to call attention to some simple numerical relations between these sets when considered as heads and tails; relations which, while they may not express the real law of the series, at least strengthen the idea that there is a definite connection between these different parts of the spectrum. The appearance of the two sets of tails has been described. The distance from the respective heads is such that we should expect the series belonging to the heads to be approaching the value λ_∞. There are five heads to the 3883 band, while there are eight tails in the group beginning at 3465. The first five tails, however, are much the stronger, and it is possible that the remaining three belong to weaker heads which are concealed by the dense structure of the 3883 band. The five tails in the group beginning at 3203, as compared with three heads in the 3590 band, may be accounted for in the same way.

Finding it impracticable to use Thiele's formulæ, owing to the difficulty in determining the constants, I have tried to find some numerical relation between these groups of heads and tails which would justify us in considering that they are connected in this way. It is found that the ratio of wave-lengths of corresponding heads and tails is constant. If we denote the wave-lengths of the heads and tails of the 3590 band by h_n and t_n respectively, and those of the 3883 band by h'_n and t'_n, then

$$\frac{h_1}{t_1}=\frac{h'_1}{t'_1}, \quad \frac{h_2}{t_2}=\frac{h'_2}{t'_2}, \quad \text{etc.}$$

Or, substituting wave-lengths, we obtain the following table:

h_n	t_n	$\frac{h_n}{t_n}$	h'_n	t'_n	$\frac{h'_n}{t'_n}$
3590.52	3203.84	1.12069	3883.60	3465.69	1.12059
3585.99	3180.58	1.12746	3871.59	3433.17	1.12770
3584.10	3160.32	1.13409	3861.91	3405.04	1.13417

Comparing the third and sixth columns of this table, we see that the corresponding ratios agree to the third decimal place.

Let us now turn our attention to the spaces above 3590 and above 3883. In each of these regions we find three dense portions very similar in appearance to the tails which we have just discussed. If these were noticed by other observers, they were probably thought to be mere condensations due to the overlapping of the lines belonging to the heads above them. They have, however, the same diffuse appearance toward the red, with sharp edges toward the violet which we noticed in the tails above 3590. The structure in this region is shown in Fig. II. The wave-lengths of these two groups are as follows:

Group III	Group IV
3658.34	3984.93
3629.06	3944.91
3603.12	3910.45

Thinking that these may be tails belonging to the two cyanogen bands with heads at 4216 and 4606, I have tried the ratios found before to see if they will still hold. Taking the successive heads of these two bands and locating their tails by means of the ratios, we find that the tails belonging to the first three heads of the 4216 band should be at 3762, 3722, and 3684. These values fall in the dense portion of the 3883 band, and it cannot be decided whether the tails are really present or not. The same is true for the tails of the first three heads of the 4606 band. They should be at 4110, 4060, and 4014; but, if present, they are concealed by the dark ground in that region. The fourth, fifth, and sixth heads of the 4216 band, however, are in approximately the same ratio to the apparent tails in Group III that the heads of the same number in the 4606 band are to Group IV, thus $\frac{h_4}{t_4} = \frac{h'_4}{t'_4}$, etc.

h_n	t_n	$\frac{h_n}{t_n}$	h'_n	t'_n	$\frac{h'_n}{t'_n}$
4165.54	3658.34	1.13864	4532.06	3984.93	1.13730
4158.22	3629.06	1.14581	4514.95	3944.91	1.14450
4152.93	3603.12	1.15259	4502.35	3910.45	1.15136

It will be seen that the agreement between corresponding ratios is not as close as in the previous case, although it is still close enough to be of interest. The photographs show no signs of tails belonging to the so-called "carbon" bands at 4737, 5165, and 5635, the condensations which sometimes occur being evidently due to a superposition of lines belonging to different series.

This peculiar structure of the cyanogen bands was observed while studying the influence of various atmospheres on the carbon arc spectrum. I am still engaged on this work, but it may be of interest to give a short account of what has been observed thus far, with its bearing on the work of others.

It was desired to obtain carbons as free from metallic impurities as possible for this work, in order not only to produce a pure spectrum of carbon, but to eliminate any effects which the presence of metals might have on the character of the carbon spectrum. As commercial carbons contain many impurities, notably iron, I have made carbons from calcined sugar by a process which, if sufficient care be taken, produces a carbon free from all troublesome foreign matter. The sugar used should be chemically pure. Thus far I have recrystallized ordinary cane sugar; but a single recrystallization does not remove all traces of the copper and calcium used in refining sugar, and as a result my photographs show the H and K lines, also the strong copper lines at 3247 and 3274. These impurities can, however, be removed by repeated solution and crystallization.

The purified sugar was calcined in a covered porcelain crucible and the resulting charcoal ground to a fine powder. The cementing material used was a saturated solution of the pure sugar in distilled water. After adding to the powdered charcoal enough of this solution to form a thick paste, it was tamped into a solid rod in a clean brass mold. The carbon rod was taken from the mold and placed in an oven, heated gently until thoroughly dried, and finally baked at a red heat for at least two hours, in order that the sugar used in cementing might be completely calcined. The rods are then hard and last fairly

well in the arc. They are, however, fragile, and are best used by fastening short pieces in the ends of metallic tubes.

The effects of atmospheres of carbon dioxide, nitrogen, and oxygen on the arc spectrum were observed. The arc was enclosed in a metallic chamber through which the gases were passed. Successive photographs of the same portion of the spectrum with the same time of exposure were taken with the arc in air and in the gas whose effect was being observed. In each case the so-called "carbon" bands at 4382, 4737, 5165, and 5635 were affected by the gas in a different way from the cyanogen bands at 3590, 3883, 4216, and 4606. The cyanogen bands were greatly weakened by the atmospheres of carbon dioxide and oxygen, as we should expect from the exclusion of the nitrogen of the air by these gases. The effect of oxygen was especially pronounced, the band at 4216 being entirely obliterated by this atmosphere. When a stream of nitrogen was passed around the arc, the cyanogen bands were slightly strengthened.

The effect of the three gases upon the "carbon" bands was the opposite of that observed with the cyanogen bands. The carbon bands were strengthened by carbon dioxide and oxygen, and weakened by nitrogen. When carbons containing metallic impurities were used in an atmosphere of oxygen, the metallic lines greatly intensified, many lines appearing which did not show at all on the plate taken in air with the same time of exposure.

Viewed in their bearing upon previous work on the carbon spectrum, these results strengthen the theory advanced by Liveing and Dewar[1] and later held by Kayser and Runge,[2] that the cyanogen bands are due to a nitro-carbon compound, though the theory of Foley[3] that nitrogen may produce this effect by its mere presence, without entering into actual combination, is worthy of consideration. As has been noted by Kayser and Runge and others, it is unlikely that cyanogen is the substance

[1] *Proc. Roy. Soc.* **30, 33, 34.**

[2] *Abh. Ber. Akad.*, 1889. [3] *Phys. Rev.*, **5**, 129, 1895.

producing the bands, on account of the high temperature of the arc. The slight intensification when pure nitrogen was passed over the arc may be explained if the amount of this element in the air is sufficient to bring the bands almost to a maximum, so that the pure gas gives but a slightly increased effect. The effect of oxygen in strengthening the metallic lines was probably due to the increased rate of vaporization of the metallic impurities, as the carbons wasted away much faster in oxygen than in air.

The "carbon" bands have evidently a different origin from the cyanogen bands, since the two sets are affected in opposite ways by the same gas. The theory of Ångström and Thalén that the "carbon" bands are due to a hydrocarbon compound has not been disproved, since the apparatus used in my work would not exclude all hydrogen from the arc. While the possibility of such an origin must be admitted, the effect of carbon dioxide on the "carbon" bands serves to support the theory recently advanced by Professor Smithells[1] that these bands are due to carbon dioxide, since the atmosphere of oxygen might be expected to form carbon dioxide and produce the intensification which was observed with both oxygen and carbon dioxide. The weakening of the "carbon" bands by nitrogen would be the natural result of the exclusion of the oxygen of the air by nitrogen.

As has been noted earlier in this paper, the banded structure, supposed to be the tails of the cyanogen bands, is affected by the surrounding atmosphere in the same way as the heads of the cyanogen bands: a fact which serves to strengthen the belief that the apparent tails are a part of the nitro-carbon spectrum.

This work was carried on under the direction of Professor Percival Lewis, to whom I am indebted for much valuable advice and assistance.

UNIVERSITY OF CALIFORNIA,
November 1901.

[1] *Phil. Mag.* (6), 1, 476, 1901.

FOCAL SINGULARITIES OF PLANE GRATINGS.

By S. A. MITCHELL.

PECULIARITIES in the focus of the spectrum from a plane grating were first called to the attention of the writer by the spectroscope used in Sumatra at the eclipse of 1901.

Mr. L. E. Jewell and the writer together observed the eclipse of 1900 at Griffin, Ga., using a plane grating spectroscope without slit. Light was reflected horizontally from the coelostat mirror and fell on the grating, where it was diffracted, and brought to a focus by a quartz lens of fifty inches focal length, interposed between grating and photographic plate. Grating, lens, and plate were mounted in a box.

The spectroscopic work of the Naval Observatory eclipse expedition this year was under the direction of Mr. Jewell. He planned to use the same grating and same box, but with a quartz lens of seventy-two inches focus, instead of the one of fifty inches. The box was not long enough to permit the lens to be inserted between grating and photographic plate, and it was, therefore, placed in the incident beam of light, fourteen inches in front of the grating. Under the supposition that the action of a plane grating is equivalent to the combined actions of a plane mirror and a dispersing apparatus, it was thought that the spectrum would be brought to a focus fifty-eight inches from the lens, the combined distances making up the focal length of the quartz lens, or seventy-two inches.

Unfortunately, there was not sufficient time for Mr. Jewell to test the action of this arrangement at the Naval Observatory before leaving for the East.

This spectroscope was one of the instruments used by the writer at Sawah Loento, Sumatra, on May 18. After setting up the instrument, and attempting to adjust and focus with the assistance of Mr. Jewell, it was found that the spectrum was not brought to a focus in the manner expected, the focusing being

accomplished with the help of a collimator which gave parallel beams of light, but from a slit source.

It was found that the "dust lines" caused by the slit, and the image of the slit caused by reflection from the grating were brought to a focus fifty-eight inches from the grating, but not so the spectrum. Making the grating normal to the incident light, and examining the spectrum of the first order from λ 3000 to λ 6000, it was found to be in focus from three to seven inches— depending on the color of the light—too far from the grating, the violet being brought to the shorter focus. If now the diffracted light is normal to the grating, and consequently, the first order on the other side is examined, the spectrum is focused from two to five inches too near the grating.

It was found impossible to use the spectroscope as arranged owing to the spectrum being so much inclined, and it became necessary to make an extension to the box to enable us to place the lens between grating and photographic plate. In this arrangement no difficulty was experienced in bringing the spectrum to a focus. Used in the latter manner, parallel beams of light are incident on the grating, and as parallel beams are diffracted.

This is the manner in which the plane grating is usually employed. To my knowledge, attention has not been called to the singularities in focus brought in by using a convergent pencil of light.

Since returning from Sumatra, my attention has been directed to an excellent article by M. A. Cornu[1] on, "A Study of Diffraction Gratings—Focal Anomalies," where he investigates the focal anomalies brought in through unequal ruling. Although he did not touch on the question of convergent light, its action can be readily found from the formula given there.

According to Cornu's equations, if the lines of the grating are equally spaced, and the radius of curvature is infinite, or the

[1] *Astronomy and Astro-Physics*, **13**, 207–215, 1894. *C. R.*, **116**, 1215–1222, 1893. See also, KAYSER, *Handbuch der Spectroscopie*, **1**. 441–446.

grating is plane, the equation in polar coördinates of the curve on which the spectrum is brought to a focus is:

$$\frac{\cos^2\gamma}{R}+\frac{\cos^2\mu}{r}=0$$

or

$$r=-R\frac{\cos^2\mu}{\cos^2\gamma}.$$

Where R and r are the distances of the source and spectrum, γ and μ the angles they make respectively with the grating normal. It may be well to call attention to the fact that the above equation is independent of the grating space and of the size of the grating.

The above equation can be directly deduced from the theory of the concave grating, published by the writer,[1] by making in the equation of the focal curve the radius of curvature equal infinity.

The grating used had 15,000 lines per inch, with a ruled space of $3\frac{1}{2}\times 5$ inches. The quartz lens was a single lens of $3\frac{23}{64}$ inches aperture, made by Brashear.

The focal lengths of this lens for the different colors, according to Mr. Jewell, are as follows:

Wave-length	Focal-length	R
λ 3000	70.8263 inches	—56.8263 inches
λ 4500	71.8814 "	—57.8814 "
λ 6000	72.2768 "	—58.2768 "

As the source is virtual, the value of R is negative, and is found by subtracting fourteen inches from each of the focal lengths, as given above.

If in the equation of the focal curve, we put $R=\infty$, then $r=\infty$: the usual method of using the plane grating.

1. If the incident light is normal to the grating, $\gamma=0$; μ can be found from the ordinary equation of the plane grating:[2]

$$\sin\gamma+\sin\mu=\frac{n\lambda}{\omega},$$

where n is the order of the spectrum and ω the grating space.

[1] ASTROPHYSICAL JOURNAL, 8, 105, 1898.

[2] See KAYSER, *Handbuch der Spectroscopie*, 1, 429.

If R is not equal to infinity, and we put, successively, values for R, γ and μ in the equation of the focal curve, we find the corresponding values of r, or the distances from the grating at which the spectrum is brought to a focus. We find these distances to be:

for λ 3000, r=55.04 inches
λ 4500, r=53.70 "
λ 6000, r=50.95 "

2. If the diffracted light is perpendicular to the grating, we get the "normal" spectrum. If μ=0 for λ 4500, by inserting values of R, γ, and μ in the equation, as before, we find:

for λ 3000, r=60.66 inches
λ 4500, r=62.17 "
λ 6000, r=62.21 "

These values represent very closely the action of the grating noticed at the Sumatra eclipse.

COLUMBIA UNIVERSITY,
November 9, 1901.

ON THE HEAT-RADIATION OF LONG WAVE-LENGTH EMITTED BY BLACK BODIES AT DIFFERENT TEMPERATURES.[1]

By H. RUBENS and F. KURLBAUM.

As is well known, W. Wien[2] has derived, from thermodynamic considerations, the following formula, which gives the intensity, E, of the radiation of a black body for all wave-lengths, λ, and all temperatures, T,

$$E = C \frac{1}{\lambda^5} e^{-\frac{c}{\lambda T}} . \tag{1}$$

More recently Mr. Planck[3] has established Wien's law upon an electromagnetic basis, so that the subject has become one of increased interest.

Up to the present, two experimental investigations of Wien's formula have been undertaken, one by Lummer and Pringsheim,[4] the other by Paschen[5] working alone, and at a later date working with Wanner. In the region of shorter wave-lengths and lower temperatures, the agreement among the results of these observers is satisfactory, but as wave-lengths become longer and temperatures higher, the discrepancies become more considerable. For instance, while Paschen always obtains exact agreement between his observations and Wien's formula, Lummer and Pringsheim find that for sufficiently high values of the product λT the deviations from this formula are very considerable. The contrast between theory and experiment is especially marked when one considers the so-called isochromatic curves, which express the intensity of radiation as a function of the

[1] From the *Sitzungsberichte der Akad. Wiss. Berlin*, Oct. 25, 1900.

[2] W. WIEN, *Wied. Ann.*, **58**, 662, 1896.

[3] M. PLANCK, *Sitzungsberichte Ber. Akad.*, 1899, p. 440.

[4] O. LUMMER and E. PRINGSHEIM, *Verhandlung der Deutschen Phys. Ges.*, I. Jahrg. S. 23 and 215, 1889; II. Jahrg. S. 163, 1900.

[5] F. PASCHEN, *Wied. Ann.*, **58**, 455, 1896; **60**, 662, 1897; *Berichte Berl. Akad.*, 1899, 405 and 959; *ibid.*, F. PASCHEN and H. WANNER, p. 5.

temperature for any given wave-length. The equation of such an isochromatic curve is, according to Wien,

$$E = \text{const.}\ e^{-\frac{c}{\lambda T}}\ .$$

In order to represent their observations by this equation, Lummer and Pringsheim were compelled to assign a variable value to the quantity c, namely for

$\lambda = 1.2\mu$	2μ	3μ	4μ	5μ
$c = 13{,}900$	14,500	15,000	15,400	16,400

For still greater wave-lengths, it was found impossible to give an even approximate description of the isochromatic curve by means of a simple exponential function. For instance, the isochromatic curve for $\lambda = 12.3\mu$ calls for values of c which range from 14,200 to 24,000 as the temperature rises; while for $\lambda = 17.9\mu$ the values of c vary from 17,200 to 27,600.

Since, now, the quantity c enters Wien's expression as an absolute constant, it is evident from the experiments of Lummer and Pringsheim that this formula is not capable of describing the facts for longer wave-lengths and higher temperatures.

Thiesen[1] has recently proposed an empirical formula, which is based upon the observations of Lummer and Pringsheim for shorter wave-lengths ($\lambda < 7\mu$), and which appears to fit the facts much better than the law proposed by Wien.

Thiesen's expression is

$$E = C \cdot \frac{1}{\lambda^5} \cdot \sqrt{\lambda T} \cdot e^{-\frac{c}{\lambda T}}\ . \qquad (2)$$

The one point of difference between this and Wien's equation is the presence of the factor $\sqrt{\lambda T}$.

Some months ago Lord Rayleigh[2] also discussed Wien's law of radiation, and pointed out the fact that it is inherently improbable, because for each wave-length it gives only finite values of intensity for infinite values of temperature. Rayleigh then proposed as a substitute

$$E = C \cdot \frac{1}{\lambda^5} \cdot \lambda T \cdot e^{-\frac{c}{\lambda T}}\ . \qquad (3)$$

[1] M. THIESEN, *Verhandlungen der Deutschen Phys. Ges.*, **2**, 37, 1900.

[2] RAYLEIGH, *Phil. Mag.*, **49**, 539, 1900.

Still a fourth general formula which includes the previously mentioned ones as special cases has been recently published by Lummer and Jahnke.[1] It runs as follows:

$$E = C \cdot \lambda^{-\mu} \; T^{5-\mu} \cdot e^{-\frac{c}{(\lambda T)^{\nu}}} \; . \tag{4}$$

Lummer and Pringsheim find that all of their observations which lie between $\lambda = 1\mu$ and $\lambda = 18\mu$ are in excellent agreement with this formula when $\mu = 4$ and $\nu = 1.3$. The difference between this expression and Lord Rayleigh's lies in the factor ν, which, in Rayleigh's equation, has the value unity. We have, therefore

$$E = C \cdot \frac{1}{\lambda^5} \cdot \; \lambda T \cdot e^{-\frac{c}{(\lambda T)^{1.3}}} \; . \tag{4a}$$

Finally, Planck,[2] since the completion of our experiments, has brought out a fifth formula, namely:

$$E = C \cdot \frac{\lambda^{-5}}{e^{\frac{c}{\lambda T}} - 1} \; . \tag{5}$$

For short wave-lengths and low temperatures this expression approaches Wien's; for long waves and high temperatures it is more nearly equivalent to Lord Rayleigh's; while it includes both as limiting cases.

Each of these equations, like that of Wien, implies Stefan's law of radiation, and also the following two relations,[3] which have been established by various observers, $\lambda_m T =$ constant and $\frac{E_{\text{max.}}}{T^5} =$ constant.[4]

[1] O. LUMMER and E. JAHNKE, *Drude's Ann.*, **3**, 283, 1900.

[2] M. PLANCK, *Berichte der Deutschen Phys. Ges.*, **2**, Oct. 19, 1900.

[3] M. THIESEN, *ibid.*

[4] In each of the six equations given above the constant c has a different value, namely:

$$\left.\begin{array}{ll} \text{In Equation (1),} & c = 5\ (\lambda_m T) \\ \text{In Equation (2),} & c = 4.5\ (\lambda_m T) \\ \text{In Equation (3),} & c = 4\ (\lambda_m T) \\ \text{In Equation (4),} & c = \frac{\mu}{\nu}\ (\lambda_m T)^{\nu} \\ \text{In Equation (4a),} & c = \frac{1}{1.3}\ (\lambda_\mu T)^{1.3} \\ \text{In Equation (5),} & c = 4.965\ (\lambda_m T) \end{array}\right\} \lambda_m T = 2890.$$

For small values of the product λT, all of these formulæ give nearly the same series of values for E; but for high temperatures and long wave-lengths the differences which characterize these various equations show themselves in a marked manner. In this case, for instance, the exponential quantities $e^{-\frac{c}{\lambda T}}$ and $e^{-\frac{c}{(\lambda T)^\nu}}$ approach unity, and we have for the isochromatic curve, according to Wien, $E=$const.; according to Thiesen, $E=$const. $\sqrt{T}$; and according to Rayleigh, Lummer-Jahnke, and Planck, $E=$const.T. Now, in view of the fact that exact measurements are limited to temperatures less than 1500° C., it is evident that this case cannot be realized experimentally, that is, we cannot pass to wave-lengths so large, and to temperatures so high that the effect of the exponential quantity will completely disappear. Not only so, but there is a limit to the length of wave which can be measured with sufficient accuracy. However, it is always possible to go much farther in this direction by using the method of residual[1] rays than by ordinary processes of dispersion. We are, therefore, in a position to determine the fitness of these various formulæ in the region of larger wave-lengths.

At the suggestion of one of us, some measurements of this kind were carried out not long ago by Mr. Beckmann.[2]

He allowed the radiation from a black body to undergo reflection at four fluorite surfaces and then measured the intensity of the residual rays for various temperatures of the radiating black body.

As was shown not long since, there is a region in the infrared — rather sharply limited — where fluorspar exhibits metallic reflection and in which two maxima occur, one at $\lambda = 24\ \mu$, the other at $\lambda = 31.6\ \mu$.

Experiment proves that after four reflections at fluorite surfaces there remain only such radiations of the black body as

[1] On the subject of residual rays, their production and their properties, see H. Rubens and E. F. Nichols, *Wied. Ann.*, **60**, 418, 1897; H. Rubens and E. Aschkinass, *Wied. Ann.*, **65**, 241, 1898; and H. Rubens, *Wied. Ann.*, **69**, 576, 1899.

[2] H. Beckmann, *Inaug. Dissert.*, Tübingen, 1898.

belong to the region of metallic reflection. This bundle of rays shows maxima of intensity at $\lambda = 24.0\,\mu$ and at $\lambda = 31.6\,\mu$. For the purpose of comparing observations with the above mentioned formulæ, we may assume that all the residual rays consist of two perfectly homogeneous radiations, one whose wave-length is $24.0\,\mu$, the other $31.6\,\mu$. Besides this, we must consider that the reflecting power of each fluorite surface at $\lambda = 21.6\mu$ is nearly 1.2 times as great as at $\lambda = 24.0\,\mu$, so that the relative intensity of the second band compared with the first is increased in the ratio $1.2^4 = 2.0$.

Beckmann, independently of the experiments of Lummer and Pringsheim, inferred from his own observations that Wien's formula could not correctly represent the facts by giving c the value 14500, which it has for short wave-lengths.

In order to obtain agreement between observed and computed values it was necessary to place[1] $c = 26000$. It was impossible for Beckmann to compare his results with the predictions of any others of the formulæ discussed in our introduction for the reason that these formulæ had not then been published.

And, indeed, Beckmann's observations were not very well adapted to test this law because the interval between his extreme temperatures is too small. The measurements begin at the temperature of solid carbon dioxide and end at about 600° C. While, as I have pointed out above, the characteristic features of these equations become marked only when we reach temperatures outside of this region and especially temperatures above this region.

We have therefore undertaken to measure the intensity of the residual rays from a black body throughout the largest possible range of temperatures. This research was made to include not only the residual rays of fluorspar but also those of rock salt which have a mean wave-length of $51.2\,\mu$. In this way we reached values of the product λT which are three times as

[1] H. Rubens, *ibid.*, p. 585. The fact that Beckmann was able to represent his observations by one of Wien's isochromatic curves is explained by the limited range of his temperatures.

great as those hitherto obtained by means of spectroscopic separation. The diagram given in Fig. 1 shows the disposition of our apparatus.

D_1 is a double-walled diaphragm through which flows water at the temperature of the room, 20° C. The diaphragm is circular in form and the aperture one centimeter in diameter. This is mounted firmly upon the table and forms what is practically the source of radiation.

In front of this diaphragm is placed a black body R in such

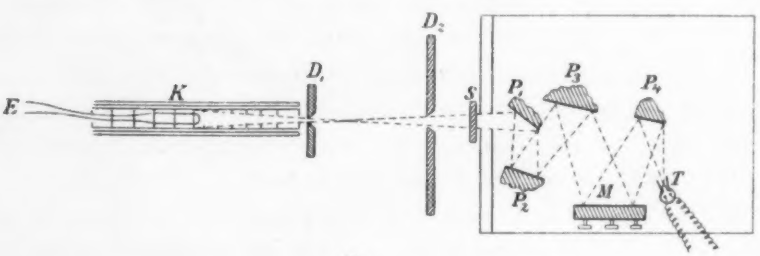


FIG. 1.

a way that its open end just fits into the aperture in the diaphragm and its axis stands at right angles to the plane of the diaphragm, adjustments which are secured by optical and mechanical devices. The rays which pass through D_1 traverse also a second diaphragm D_2, which limits the cone of rays in such a way that only those from the innermost part of the black body can get through. Farther on in the path of the rays is placed a double-walled screen, through which also flows water from the same supply as that in D. Still farther on in the path of the rays are the reflecting surfaces, P, of fluorspar or rock salt, as the case may be, a condensing mirror, M, silvered on the front, and the thermopile, T.[1] These latter parts of the apparatus are protected against outside radiation and air currents by being placed in a case. The thermopile was connected to a galvanometer of the shielded[2] form ("*Panzer Galvanometer*") whose sensibility was constantly under control by means of a simple

[1] H. RUBENS, *Zeitschrift für Instrumentenkunde*, **18**, 65, 1898.

[2] H. DU BOIS and RUBENS, *Drude's Ann.*, **2**, 84, 1900.

device. Changes in sensibility were always taken into account in the computation of our results.

The impurities of the residual rays consist of heat rays which, in composition, are practically the same as the total radiation of the black body. Accordingly the intensity of the impurities must approximately obey Stefan's law and increase with the fourth power of the temperature, while the intensity of the residual rays varies directly as the first power of the temperature. It follows, therefore, that the relative impurity increases as the third power of the absolute temperature of the black body.

While four reflecting surfaces were found sufficient to isolate the residual rays of fluorspar with a fair degree of purity, it was discovered that this number of surfaces was not competent to separate the very weak residual rays of rock salt. By the use of five surfaces we obtained residual rays of satisfactory purity up to temperatures of 600° C., at which the impurity due to ordinary heat radiation amounted to 10 per cent. By the introduction of a sixth rock salt surface the impurity was reduced to about $\frac{1}{20}$. But at temperatures higher than 1000° C. it was again marked and at the highest attainable temperature 1474° C. amounted to almost 8 per cent. of the quantity being measured. We did not therefore attempt to further increase the number of reflecting surfaces, but preferred rather to determine exactly what correction was necessary to compensate for the impurity of the radiation. This was done by means of a rock salt plate which completely absorbed the residual rays while it transmitted 90 per cent. of the impurity.

In the experiments with fluorspar we employed four different black bodies which had already been used in other investigations at the Reichsanstalt.[1] The first of these (I) was a hollow radiating body so arranged as to be cooled by a stream of liquid air flowing over it. The second (II) was so arranged that it could be filled with solid carbon dioxide and ether. The

[1] O. Lummer and F. Kurlbaum, *Verhandlungen der Berliner Phys. Ges.*, 17, 106, 1898; and *Thätigkeitsbericht der Phys. Tech. Reichsanstalt*, p. 38. 1899.

third (III) was heated by steam, and the fourth (IV) by an electric current. This last was the only one used in the fluorspar experiments between 300° C. and 1500° C. In order to get the exceedingly feeble residual rays of rock salt, especially at low temperature and with sufficient accuracy, we removed the diaphragm D_1 (Fig. 1), and placed successively the first three of the black bodies immediately in front of the diaphragm D_2.

This was admissible since these three black bodies each possessed an aperture greater than that of D_2. The electrically heated black body (IV) had an aperture of only 12 mm, so that we were compelled in this case to use also the diaphragm D_1 as indicated in Fig. 1.

We have therefore constructed for this investigation two more electrically heated black bodies which, like bodies I, II, and III, have sufficiently large linear apertures (30 mm) and emit sufficiently large cones of rays to be used immediately in front of diaphragm D_2.

One of these (V) was made of "Marquardt's substance" wrapped with a platinum band and could be used in the region of temperatures lying between 300° C. and 1500° C. The other (VI) was made of iron, blackened with iron oxide, and was heated by means of an electric current passing through a spiral of nickel. The highest temperature to which this body could be heated was 600° C. Accordingly it has been used only between temperatures 300° and 600° C.

As noted above, the black body IV was employed, in connection with the diaphragm D_1, for temperatures higher than 500° C. The deflection thus obtained was 7.5 times smaller than that obtained from bodies V and VI placed in front of diaphragm D_2. Deflections obtained with the body IV were therefore multiplied by this factor in order to make them comparable with other observations.

This numerical factor was determined by making the deflections due to bodies IV and V equal at a given temperature, approximately 1000°. On account of the smallness of the

deflections produced by IV it is evident that the observations made on this body are much less accurate than the others. Nevertheless they are valuable as checks.

In Fig. 3 the points obtained by observation upon each of these different bodies are indicated by a different mark.

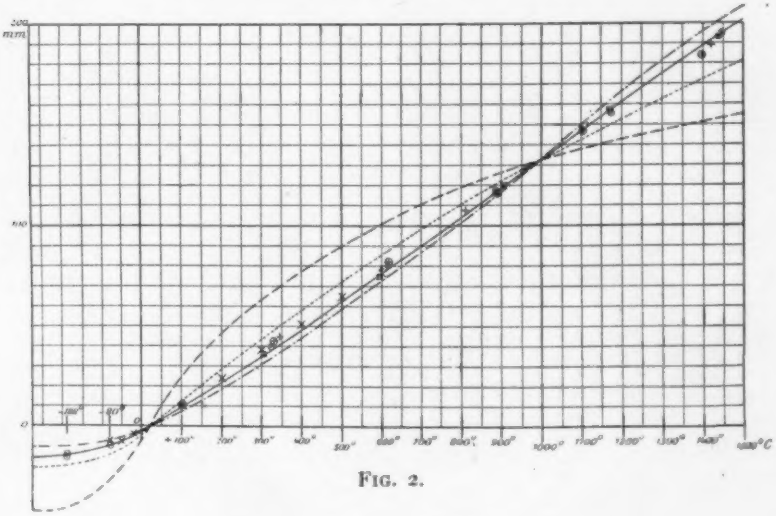


FIG. 2.

------ $E = f(t)$ calculated according to Wien.
.... $E = f(t)$ calculated according to Thiesen.
.._._._ $E = f(t)$ calculated according to Lord Rayleigh.
——— $E = f(t)$ calculated according to Planck.

× × × Observations of Beckmann.
● ● ● Observations of Rubens and Kurlbaum with sylvine plate.
+ + + / ○ ○ ○ / □ □ □ Series of observations of Rubens and Kurlbaum without sylvine plate with different adjustments of the fluorite surfaces.

In the case of the electrically heated bodies the temperatures were determined as usual by a Le Chatelier thermopile (*E*, Fig. 1) based upon the latest results of Holborn and Day.[1]

In Fig. 2 are shown the results of our observations on the residual rays of fluorspar, and in Fig. 3 those for rock salt, that is, the observed deflections are plotted as a function of the temperatures of the radiant bodies. And, by the use of different signs,

[1] L. HOLBORN and A. DAY, *Wied. Ann.*, **68**, 817, 1899.

four entirely independent sets of observations, made on different days and after independent adjustment of the fluorspar surfaces, are represented in Fig. 2.

In one of these sets where the individual observations are indicated by a point surrounded by a small circle (thus ⊙) a plate

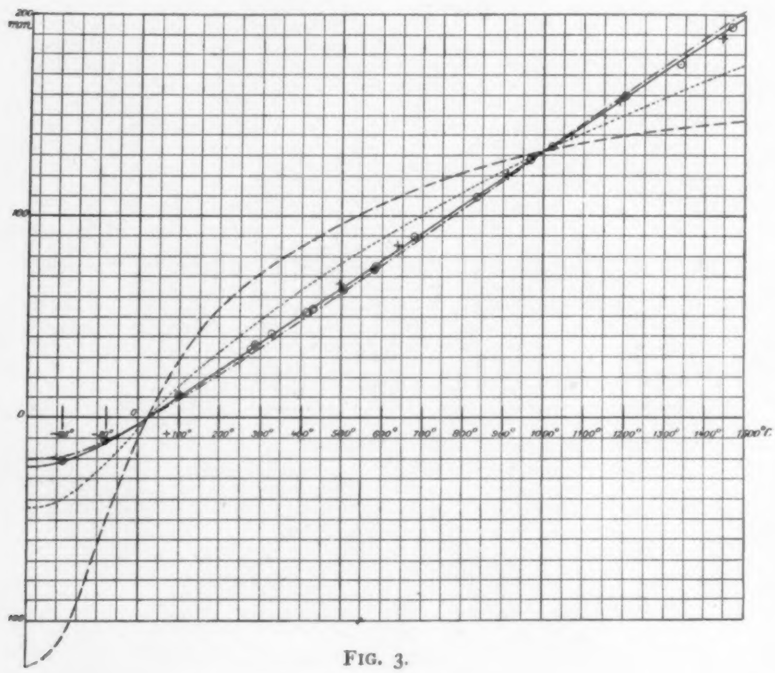


FIG. 3.

_ _ _ _ _ $E = f(t)$ calculated according to Wien.
.... $E = f(t)$ calculated according to Thiesen.
_ _ _ . _ $E = f(t)$ calculated according to Lord Rayleigh.
———— $E = f(t)$ calculated according to Planck.

● ● ● Observed with Black Bodies I, II, and III.
○ ○ ○ Observed with Black Body IV.
+ + + Observed with Black Body V.
⊙ ⊙ ⊙ Observed with Black Body VI.

of sylvine 2 mm thick was placed in the path of the rays immediately in front of the thermopile. This served to completely absorb the long waves among the residual rays while it

transmitted[1] nearly half of that radiation which has its maximum at $\lambda = 24.0\mu$.

In this manner the influence of the second absorption band was completely eliminated. Yet the results of this series show that the intensity of radiation varies with temperature in practically the same manner as when the plate of sylvine is not used.

This series coincides however more exactly with the others when each ordinate is multiplied by the constant factor 2.80, as has been done in Fig. 2.

Finally a smooth curve—the solid line in Fig. 2—was drawn connecting all the points determined by observation. In the region of low temperatures ($-188°$ to $0°$) this curve exhibits marked curvature, being concave on the upper side. Farther on this curvature disappears almost completely and the curve becomes rectilinear. In other words, the residual rays between $0°$ and $1500°$ increase in direct proportion to the difference of temperature between the body which emits and the body which absorbs the radiation. The same is also true for rock salt, as is evident from Fig. 3, where the curve also begins with a slight concavity on the upper side and soon becomes rectilinear. For the sake of more easily comparing the curves of Figs. 2 and 3, we have given them each the same ordinate[2] at the temperature of $1000°$ C. And, as is evident, they differ very little for other temperatures.

In order to make possible a comparison of our results with those of Beckmann we have reduced his results to our scale and have plotted them in Fig. 2, where they are indicated by an asterisk (thus *). The agreement, as will be seen, is very satisfactory: and this coincidence is all the more important, since Beckmann's observations were confined to one black body while ours in the interval in question ($-80°$ to $600°$) were made upon three different bodies. It may therefore be considered as proved that the various bodies employed by us behave in the

[1] H. RUBENS and A. TROWBRIDGE, *Wied. Ann.*, **60**, 724, 1897; also H. RUBENS and E. ASCHKINASS, *Wied. Ann.*, **65**, 253, 1898.

[2] The numerical value of the ordinates in the figures are so chosen that they are very nearly the actual deflection in millimeters produced by the residual rays of rock salt.

same way so far as an approximation to Kirchhoff's ideal black body is concerned. From Fig. 3, the same appears to be true also for rock salt. For here the black bodies IV, V, and VI give, within the limits of error, the same deflections throughout the range of temperatures in which they could be compared namely, from 275° to 600° and from 500° to 1500°.

Besides the results of direct observation, Figs. 2 and 3 contain also three other curves showing the dependence of residual rays upon temperature, according to the formulæ proposed by Wien, Thiesen, and Lord Rayleigh. A fifth curve exhibiting this same function according to the formula of Lummer and Jahnke, using the constants $\mu = 4$ and $\nu = 1.3$, can be shown only for the lower temperatures, since it coincides almost perfectly with our observed curve. This is the formula which Messrs. Lummer and Pringsheim employed to represent their work. For the same reason it is impracticable to plot Planck's formula (5) in Figs. 2 and 3, since his expression agrees perfectly with our observations, not only from 0° to 1500,° but also from $-188°$ to 0°, at least to within errors of observation. The small deviations between our experimental results and the predictions of formulæ (4^a) and (5) may easily be seen from the following tables. The scales of all the curves are so chosen as to make the ordinates at 1000° exactly the same. In the computation of the curves for Fig. 2 we have always corrected for the presence of the band at $\lambda = 31.6\mu$, although the form of the curve would scarcely be affected if we were to neglect it entirely, and assume that the radiation is confined to a single band at $\lambda = 24\mu$. For temperatures above 0°, these deviations could scarcely be seen on the scale chosen for Fig. 2, since they are all less than 1 mm. They amount to an appreciable quantity only for very low temperatures, but for the sake of avoiding complication they are not shown in the diagram.

A glance at these curves is sufficient to prove that none of the formulæ of Wien, Thiesen and Rayleigh is capable of describing the results of observation within the limits of experimental error. Rayleigh's formula fits our results most closely,

while that of Wein is the least adapted.[1] On the other hand, the deviations of our figures from the formula of Lummer and Jahnke (4^a) are very slight. These deviations become as great as the errors of observation only in the case of very low temperatures, where the deflections are 20 per cent. smaller than the computed values. For temperatures of the black body between 0° and 1500° C. the coincidence is perfect. We have already called attention to the fact that Planck's formula (5) describes our experiments for all temperatures.

In the two following tables are collected the interpolated values of the observed deflections for various temperatures, together with the values predicted by the formulæ (1), (2), (3), (4^a), and (5) both for the case of fluorspar and for the case of rock salt.

The most marked difference between formula and experiment is in the case of Wien's values for the residual rays of rock salt. At the temperature of liquid air the deflection observed is only about one-fifth of that computed, while, on the other hand, the deflection observed (194 mm) at 1474° is the

TABLE I.

Residual rays of fluorspar, $\lambda = 24.0\mu$ and 31.6μ.

Temperature Centigrade t	Absolute Temperature T	E Obs.	E according to Wien	E according to Thiesen	E according to Rayleigh	E according to Lummer and Jahnke	E according to Planck
− 273	0	....	− 42.4	− 20.7	− 10.7	− 17.8	− 15.4
− 188	85	− 15.5	− 41.0	− 20.2	− 10.5	− 17.5	− 15.0
− 80	193	− 9.4	− 26.8	− 14.0	− 7.4	− 11.5	− 9.3
+ 20	293	0	0	0	0	0	0
+ 250	523	+ 30.3	+ 50.6	+ 35.7	+ 25.3	+ 30.0	+ 28.8
+ 500	773	+ 64.3	+ 88.9	+ 71.8	+ 58.3	+ 64.5	+ 62.5
+ 750	1023	+ 98.3	+114	+104	+ 94.4	+ 98	+ 96.7
+1000	1273	+132	+132	+132	+132	+132	+132
+1250	1523	+167	+145	+157.5	+174.5	+167	+167.5
+1500	1773	+201.5	+155	+181	+209	+201	+202
+ ∞	∞	....	+226	+ ∞	+ ∞	+ ∞	+ ∞

[1] The single point of intersection chosen for these curves, namely, $t = 1000°$ C. is selected for the purpose of making the divergence between theory and experiment as small as possible. If these curves had been made to coincide at $t = 1500°$ C., the discrepancy would have been much more marked.

TABLE II.

Residual rays of rock salt, $\lambda = 51.2\mu$.

Temperature Centigrade t	Absolute Temperature T	E Obs.	E according to Wien	E according to Thiesen	E according to Rayleigh	E according to Lummer and Jahnke	E according to Planck
− 273	0	....	−121.5	− 44	− 20	− 27	− 23.8
− 188	85	− 20.6	−107.5	− 40	− 19	− 24.5	− 21.9
− 80	193	− 11.8	− 48.0	− 21.5	− 11.5	− 13.5	− 12.0
+ 20	293	0	0	0	0	0	0
+ 250	523	+ 31.0	+ 63.5	+ 40.5	+ 28.5	+ 31	+ 30.4
+ 500	773	+ 64.5	+ 96	+ 77	+ 62.5	+ 65.5	+ 63.8
+ 750	1023	+ 98.1	+118	+106	+ 97	+ 99	+ 97.2
+1000	1273	+132	+132	+132	+132	+132	+132
+1250	1523	+164.5	+141	+154	+167	+165.5	+166
+1500	1773	+196.8	+147.5	+175	+202	+198	+200
+ ∞	∞	....	+194	+ ∞	+ ∞	+ ∞	+ ∞

limiting value set by Wein's formula for an infinitely high temperature, assuming the scale which we have here employed.

In any event, it is evident from the preceding results that only those formulæ which make the radiation E vary directly as the temperature T, are competent to describe the behavior of a black body for large wave-lengths and high temperatures. Such formulæ are those of Lord Rayleigh, Lummer-Jahnke ($\mu = 4$) and Planck.

Of these three formulæ, however, only the last two are to be considered, since Lummer and Pringsheim have shown that Rayleigh's expression does not represent the facts in the case of short wave-lengths. In comparison with our observations, also, it shows considerable systematic deviation. We find, therefore, that so far as the representation of Lummer and Pringsheim's results, as well as our own, is concerned, the formulæ (4^a) and (5) are excellently adapted, but that Planck's expression, in so far as it does the same thing, deserves the preference on account of its simplicity.

[Shortly after the publication of this article in the *Proceedings of the Berlin Academy*, it appeared in a somewhat amplified form in *Drude's Annalen*, **4**, 649–666 (1901). The principal change from the present article consists in addition of an isochromatic curve for wave-length $\lambda = 8.85\mu$, determined by the measurement of residual rays reflected from quartz. The isochromatic thus obtained confirms the conclusions which the authors had already drawn from their observations on rock salt and fluorspar.]—Ed.

Minor Contributions and Notes

PRELIMINARY REPORT OF OBSERVATIONS OF THE TOTAL SOLAR ECLIPSE OF 1901, MAY 17–18.[1]

THROUGH the generosity of Mr. William H. Crocker, of San Francisco, it was possible for the Lick Observatory to send an expedition to Sumatra to observe the total solar eclipse of May 17–18, 1901, thus continuing, unbroken, the series of expeditions begun upon the opening of the Observatory in 1888.

The great duration of the eclipse and the high altitude of the Sun promised many advantages in the solution of a number of problems, and rendered it extremely desirable to take advantage of the event.

The expedition left San Francisco on February 19, traveling by the regular lines of steamers, and reached the city of Padang, on the west coast of Sumatra, on April 5.

After consulting with the Dutch officials, the abandoned race-course in the northern portion of Padang was selected as a site for the station. Its approximate position was

Longitude $6^h\ 41^m\ 20^s$ East of Greenwich.
Latitude $0°\ 56'$ South.

The work planned for was as follows:

1. Large scale photographs of the corona with the fixed telescope of 40 feet focal length, designed and used first by Professor Schaeberle in Chile in 1893.

2. Photographs of the corona with the Floyd telescope of 5 inches aperture and $70 \pm$ inches focal length.

3. Photographs of the corona with the Pierson[2] (Dallmeyer) camera of 6 inches aperture and 32.6 inches focal length.

4. Photographs in duplicate of the region about the Sun, for the detection of any small planets with orbits interior to that of *Mercury*. These photographs were to be secured with four telescopes of 3 inches

[1] *Lick Observatory, University of California, Bulletin* No. 9.

[2] This portrait lens is the property of Hon. W. M. Pierson, of San Francisco, and has been very kindly loaned by him for a number of eclipse expeditions.

aperture and 11 feet 4 inches focal length, covering a region 18° on either side of the Sun in the direction of its equator and 5½° wide.

5. A single photograph of the spectrum of the corona with a spectrograph containing one light flint 60° prism, and having the slit north and south across the corona about 2′ east of the Sun's east limb.

6. A single photograph of the spectrum of the corona, using a spectrograph similar to the preceding, but with the slit directed east and west across the Sun's center. Both of these instruments were designed especially to record any Fraunhofer lines existing in the corona.

7. Photographs of the entire corona with a camera of 20.75 inches focal length, having a double image prism of 1 inch aperture placed in front of the objective. Two exposures were to be made in each of five positions of the prism, 22½° apart, the first exposure being made with the principal plane of the prism parallel to the Sun's equator.

These photographs should show polarization in the light of the corona, if any appreciable percentage were polarized in a given plane.

The 40-foot telescope was mounted as at former eclipses, *i. e.*, pointing directly at the Sun.

The four intra-mercurial telescopes were fastened together rigidly, and mounted equatorially. As the position of the telescopes had to be changed during the eclipse to cover different regions of sky not along the direction of diurnal motion, they were mounted directly on a second axis perpendicular to the plane of the Sun's equator.

The remaining five instruments were all attached to a long polar axis, and driven by one clock.

All of the ten instruments were mounted and in adjustment by May 12. The remainder of the time before the eclipse was devoted to drilling the observers, to checking the many adjustments of the various instruments, and to the arrangement of the final details.

Eclipse day dawned with a sky covered with light cirrus clouds, which condition continued with but little variation throughout the morning. At the time of first contact the Sun shone through an almost clear space between clouds. As totality approached, a clear sky was visible off near the northern horizon, but light clouds and haze still covered the sky above our station. The clouds were considerably thicker toward the end of totality than they were during the first half, all of the corona negatives showing marked diminution in

light. Shortly after totality the clouds began to dissipate, and before 2 o'clock the sky overhead was perfectly clear.

While the clouds interfered to a certain extent with some of the observations, others have proved to be as satisfactory as if the sky had been perfectly clear. The negatives of the inner and middle corona, with both the 40-foot and the Floyd telescopes, show all the detail that would have been secured in a clear sky. The same is equally true of the polariscopic and spectroscopic results. In fact, the cloudiness was a benefit, rather than a detriment, to these last investigations, bringing out some features which otherwise would have been lost through over-exposure.

The intra-mercurial planet search suffered the most severely from the clouds, but the plates will perhaps enable a more far-reaching conclusion to be drawn as to the maximum brightness which any such bodies can have, than has heretofore been possible,

The apparatus and the negatives were shipped from Padang on May 29, and in the natural course of events should have reached home before August 1. Unfortunately, the packages were delayed at some port en route, at present unknown, and did not arrive at Mount Hamilton until October 11. The photographs made the trip without accident, and are all in good condition.

The complete program of observation, with a brief preliminary statement of the results secured, is given below.

LIST OF NEGATIVES.

No.	Instrument	Size of plate	Kind of plate	Exposure	Remarks
1	40-foot camera	8 ×10	Carbutt B	½s	Good.
2		14 ×17	Seed 27	1	Good. Detail off E. limb well shown.
3		14 ×17	Seed 27	2	Good. Detail off E. limb well shown.
4		14 ×17	Seed 27	4	Good. Corona to 15′.
5		14 ×17	Seed 27	16	Good. Corona to 15′.
6		18 ×22	Seed 27	40	Good. Corona to 20′.
7		18 ×22	Seed 27	150	Good. E. streamer to fully one and one-third diameters.
8		14 ×17	Seed 27	4	Good. But little corona.
9		14 ×17	Seed 27	25	Good. About the same extension as No. 3
10		14 ×17	Seed 27	8	Good. Much less than Nos. 3 and 4.
11		14 ×17	Seed 27	1	Good.
12		8 ×10	Carbutt B	½	First flashes of returning sunlight.
1	Floyd, 70-inch	5 × 7	Seed 27	½	Good. Streamers to 10′.
2			Seed 27	2	Good. Eastern extension to one diameter
3			Seed 27	8	Good.

LIST OF NEGATIVES.—*Continued.*

No.	Instrument	Size of plate	Kind of plate	Exposure	Remarks
4	Floyd, 70-inch	5 × 7	Seed 27	4	Good. Streamers to 25′.
5			Carbutt B	60	Good. Streamers to over a diameter.
6			Seed 27	20	Good. Extensions only 15′.
7			Seed 27	2	Good. Extensions only 5′.
8			Seed 27	½	Good.
1	Pierson (Dallmeyer)	8 × 10	Seed 27	½	Eastern streamers to one diameter.
2			Seed 27	2	Eastern streamers to one diameter.
3			Seed 27	8	Eastern streamers to one diameter.
4			Carbutt B	30	Over-exposed.
5			Seed 27	4	Slide not drawn.
6			Carbutt B	60	Over-exposed. E. streamer to 1¼ diam.
7			Seed 27	20	Slide not drawn.
8			Seed 27	10	Corona to 20′.
9			Seed 27	2	Caught by returning sunlight.
10			Seed 27	½	Not exposed.
A 1	Intra-mercurial	14 × 17	Seed 27	90	28 stars. Faintest = 8.8 visual magnitude.
B 1					
C 1					37 stars. Faintest = 8.6 visual magnitude.
D 1					
A 2				90	27 stars. Faintest = 8.8 visual magnitude.
B 2					
C 2					No star images.
D 2					
A 3				75	No star images. Inner corona and *Mercury* and *Venus* are distinct.
B 3					
C 3					No star images.
D 3					
1	Spectrograph I (Slit tangential)	2⅛ × 3¼	Cramer Crown	320	Good.
1	Spectrograph II (Slit Radial)	2⅛ × 3¼	Cramer Crown	320	Good.
	Polarigraph	3¼ × 4¼			
1	Setting 0°		Cramer Cr.	1	Negative good.
2				10	Slide not drawn.
3	22½			1	Negative good.
4				10	Negative good.
5	45			1	Negative good.
6				10	Negative good.
7	67½			1	Negative good.
8				10	Negative good.
9	90			1	Negative good.
10				10	Negative good.

PHOTOGRAPHS OF THE CORONA.

The negatives secured with the 40-foot and Floyd telescopes show the inner corona as well probably as if there had been no clouds to

interfere; but the longest recorded streamers are limited to about one and one third solar diameters. The corona is of the minimum type. Without describing the photographs in detail, attention may be called to an especially conspicuous series of coronal hoods surrounding a prominence in position angle 115°, and to a remarkable disturbance in the northeast quadrant of the corona. The latter is near position angle 65°. At this point on the limb is a small compact prominence, over which there is a disturbed area resembling roughly an inverted cone of large solid angle. The apex of this area is not visible; it seems to lie below the chromospheric layer showing at the limb, as if the apex were at some distance in front of or behind the limb. From the apparent position of the apex a number of irregular streamers and masses of matter radiate as if thrown out by an explosion. A long thread-like prominence to the south of this point appears to emanate from the same source. The corona above and around this region is composed of broken, irregular masses, much like those seen in photographs of the Orion and other similar nebulæ. So far as I am aware, no such disturbance in the corona proper has been observed before.

INTRA-MERCURIAL PLANET SEARCH.

The results given in the table for the intra-mercurial plates are derived from an inspection at the station in Sumatra. A more thorough examination will be given them later. It is possible that more stars will be found, and that some images may be detected on the negatives marked as having none.

The performance of these lenses[1] has been very satisfactory. There is but little distortion on any part of a 14 × 17 plate; and, with a clear sky, stars of 9½ to 10 magnitude could undoubtedly have been photographed in the 90 seconds. A 4-inch aperture of the same focal length could be used without the darkening of the plates becoming objectionable in exposures of two minutes or less, and with considerable gain in light power.

POLARIGRAPH.

The first exposures secured with this instrument show the equatorial extensions of the corona to a distance of one diameter; toward

[1] These lenses for intra-mercurial planet work were designed by Professor W. H. Pickering. Two of those used in Sumatra were loaned by Professor E. C. Pickering, Director of the Harvard College Observatory.

the end of totality only about one quarter of a diameter is shown, owing to increased cloudiness.

The negatives indicate a large percentage of polarization in the light of the corona beyond 10′ from the solar limb. This is true of all position angles, including the regions containing the polar streamers.

The last exposures point to a relatively small amount of polarized light in the inner corona.

SPECTROGRAPHS.

The two spectrographs (as well as the polarigraph) were designed and prepared for use by Director Campbell and Assistant Astronomer W. H. Wright. The negatives secured show both instruments to be very efficient for the purpose of recording dark lines in the spectrum of the corona. Had the sky been free from clouds the spectrum of the inner corona would have been over-exposed.

Spectrograph with tangential slit.— The slit was placed north and south across the corona about 2′ east of the Sun's east limb. The negative shows a width of spectrum of rather over a solar diameter and covers the region from $\lambda 490$ to $\lambda 360 \pm$.

The H and K lines are bright and quite strong, the latter having the greater intensity. No doubt these are due to calcium radiations from the prominences diffused in our sky. No other bright lines are shown. The continuous spectrum is strong, but not so dark as to obliterate the details. There are several stronger bands extending longitudinally through the speotrum, which are due in all probability to the brighter condensations in the corona proper. Many Fraunhofer lines are visible, especially between $H\gamma$ and K, and can be traced across the full width of the spectrum. They are less distinct where they cross the dark belts mentioned above. The disturbed area already spoken of fell across the slit of this spectrograph. Comparisons with a sky spectrogram secured with the same instrument show that the coronal and sky spectra are sensibly identical in the blue and violet regions.

Radial slit spectrograph.— In this spectrograph the slit was placed east and west across the Sun's center. The negative shows practically the same range of spectrum as the preceding one, and extends on either side of the Moon's disk to over a diameter. The image of a prominence on the east limb of the Sun covered the slit, producing

very bright over-exposed H and K lines, as well as the other characteristic prominence lines. On either side of the Moon's disk is a band of continuous spectrum about 8′ in width without any trace whatever of dark lines. Outside of this band 35 Fraunhofer lines can be counted between $H\beta$ and H, extending out to the limit of the spectrum. The dark lines visible lie almost wholly between these limits, beyond which there is but little trace of the spectrum of the outer corona. A longer exposure would probably have shown all the Fraunhofer lines observable with the slit-width and dispersion used. As in the case of the other spectrograph, a comparison was made with a negative of the sky taken with the same instrument, and the same agreement was noted.

Bright H and K lines of good strength extend entirely across the Moon's disk, and to a distance of about 40′ east of the Sun's limb, but they show only feebly on the west side of the Sun. They are symmetrical with reference to the image of a prominence on the east limb, indicating a diffusion in our atmosphere of calcium radiations from that source. A consideration of all the facts shows that the clouds have not affected these results, nor their interpretation.

Professor Campbell has examined these spectrograms, and confirms the above results.

It should be noted that Professor Campbell's spectrographic observations at the India eclipse of 1898 also showed no trace whatever of dark lines in the inner corona, the spectrum only extending to a distance of 2′.5 from the limb, however. The Indian results were obtained with high dispersion, using four light prisms in one case, and six dense prisms in another.

The preceding observations seem to point to a very definite explanation of the general constitution of the Sun's corona. The spectroscopic and polariscopic results agree in showing that the light of the outer corona is in great measure reflected sunlight, whereas the spectrograph shows the light from the inner corona to emanate largely from incandescent matter. These facts, taken in connection with the varying appearance of the corona, suggest as the most reasonable explanation that matter, probably very finely divided, is ejected from the surface of the Sun with great velocity, giving rise to the streamers and extensions observed. This matter may or may not be solid when it first leaves the Sun, but observation indicates that it is incandescent, and probably largely solid, when it first becomes visible above the

layer of chromosphere. While in this state, its inherent light would in all probability be much greater than the light reflected from the solar surface; but a point would be reached in its outward journey where it would become cool enough for the reflected light to be observable. While actual radial motion has not been observed in the corona proper, appearances point far more strongly to a condition of great movement than to a state of comparative rest.

The well-known bright lines observed on many occasions in the corona indicate, also, an irregular but comparatively thin gaseous envelope about the Sun. However, the quantity of light contained in the bright-line spectrum is very small in comparison with that composing the continuous spectrum; and it is probable that the gaseous envelope does not appreciably affect the ordinary photographs of the corona.

It should be noted that the explanation suggested above, deduced through a different train of reasoning, from an entirely distinct set of facts, is in accord with the conclusion reached by Professor Schaeberle from a study of the forms of the coronal streamers shown in his large scale photographs of the 1893 eclipse, that these streamers are composed of matter ejected from the Sun, with great velocity.

TIMES OF CONTACTS.

The first three contacts were observed by me as follows;

	h	m	s	
I	22	45	30.9	mean time of station.
II	0	18	52.3	
III	0	25	1.3 ± 1^s	

Observed duration of totality, $6^m\ 9^s.0$.

The following are the times of the contacts for the station, computed from the data given in the American *Ephemeris*:

	d	h	m	s	
Beginning of eclipse	May 17	22	45	16.1	mean time of station.
Beginning of totality	May 18	0	18	49.9	
End of totality	May 18	0	24	56.8	
End of eclipse	May 18	1	57	25.5	

Computed duration of totality, $6^m\ 6^s.9$.

Contact I was observed with the sextant, and is probably 2^s or 3^s later than geometrical contact. Contacts II and III were observed without optical aid. Contacts I and II were timed directly from the

chronometer; contact III, by means of the counts of the timekeeper, and is subject to a possible uncertainty of a second. As soon as possible after totality, the counts were compared directly with the chronometer. The corrections to the chronometer were determined from sextant observations of the Sun.

The time observation secured after the eclipse indicated a considerable change of rate of the chronometer subsequent to the observation of the same morning. About ten minutes before the beginning of totality the chronometer was removed from the shelter, where it had remained undisturbed on a pier, in order to permit the timekeeper to have a view of the eclipse, and replaced in its original position shortly after totality. In determining the chronometer corrections for the times of the contacts, it has been assumed that the change of rate occurred with the change of position of the chronometer.

SHADOW BANDS.

The conditions of the sky were unfavorable for observations of the shadow bands. Mr. Lagerwey, however, detected faint bands at the beginning of the eclipse. These bands had wavy outlines at first changing to almost straight toward the end of their apparition. The direction of the wave front was north 60° east and south 60° west, the waves moving in a direction at right angles to the wave front.

THE GREAT SOUTHERN COMET.

On May 4 a telegram was received from Professor Skinner announcing that a brilliant comet had been observed by Mr. Dinwiddie at Solok, in the western sky just after sunset of the previous evening. The evening of May 4 was cloudy at Padang, but the evening of May 5 was clear; and the comet was seen low in the west against a very bright sky. Sextant observations were secured of its position, using the nearest available stars. As the sky darkened, it became a very conspicuous object. It had a brilliant nucleus, and a tail 6° to 8° in length. The Pierson camera was mounted on the following day and directed to the place of the comet. Owing to the brightness of the sky and to the lack of means for following the comet, only short exposures were attempted. Four negatives were secured on May 6, as follows:

	Duration of exposure	Length of tail
No. 2_2	1 m	3°
4_2	3	3½
1_4	7	4
1	0 m 30 s	

The last plate contained no image owing to the haze and the proximity of the comet to the horizon.

The principal tail was composed of two slightly curved and nearly parallel streamers. The second and third negatives show a very faint streamer to the south, making an angle of 35° with the axis of the principal tail.

Clouds near the western horizon prevented any further observations or photographs, although the instruments were left in readiness, until it became necessary to adjust them for the eclipse.

Mr. Ralph H. Curtiss, formerly assistant in the Students' Observatory, University of California, was appointed assistant in the Lick Observatory from February 15, and accompanied the expedition, helping throughout in the work of preparing the station and in the observations.

The most cordial aid was extended to the expedition in all possible ways by the officials and citizens of Padang, and I am largely indebted to them for the results obtained. Especial thanks are due to His Excellency, Governor Joekes, for information and introductions to heads of departments, as well as for protection during our stay; to Kolonel H. F. C. Van Bijlevelt, commander of the army in Sumatra, who detailed a number of his officers to take part in the observations; to Major Muller, of the general staff N. I. army, for advice as to the choice of a station; to Assistant Resident Hartogh Heiss, head of the police department of Padang, who obtained trustworthy watchmen, conducted some of the business negotiations, furnished a large detail from his force to do guard duty on the day of the eclipse, and had the immediate responsibility for the safety and quietness of the camp; to Heer Th. F. A. Delprat, head of the government railways of Sumatra, for free transportation for observers and freight, for the detail of skilled workmen from the very extensive railway shops, for the facilities of a complete photographic dark room, for his assistance throughout the observations and for his counsel and help in practical matters at all times; to Heer F. Bouman, superintendent of construction of the railways, for his oversight of the construction of the necessary structures and shelters required at the station, as well as for his assistance throughout the observations.

Those who took part in the work of observation were: Heer Th. F. A. Delprat; First-Leutenant der genie P. L. de Gaay Fortman; Second-Leutenant der Infanterie W. H. Warnsinck; Second-Leutenant der

Infanterie E. Sieburgh; Mevrouw de Gaay Fortman, Heer J. Kempens, Heer F. Bouman, Heer van Leeuwen Boonkamp, Heer van der Straeten, Heer Junius, Heer Cleton, Heer Nieuwenhuys, Heer Guldenaar, Heer d'Hanens, and Heer Lagerwey.

The greatest enthusiasm was manifested by all in the preliminary rehearsals as well as in the observations on eclipse day.

Favors were shown to the expedition in all possible ways, from Mt. Hamilton to Padang, every one being not only willing but anxious to aid. Among these especial mention should be made of Mr. Robert Bruce, of the firm of Balfour, Guthrie & Co., of San Francisco; the Toyo Kisen Kaisha; the Occidental and Oriental Steamship Company; the Pacific Mail Steamship Company; the officers of steamship "Nippon Maru;" and Mr. Aubrey Fair, of Hongkong; Mr. A. I. Ross and Mr. T. Scott, of the firm of Guthrie & Co., Singapore; the agents and officers of the "Koninklijke Paketvaart-Maatschappij" and "Stoomvaart Maatschappij Nederland;" the representatives of the firm of J. Daendels & Co., in Singapore, Batavia, and Padang; the officers of the Hongkong and Shanghai Bank, in San Francisco and Batavia, and of the Java Bank in Padang; Heer C. G. Veth, the American Consul in Padang.

It is planned that a full report of the observations, with reproductions of some of the photographs, shall appear as early as possible, in a volume of the publications of the Lick Observatory.

C. D. PERRINE,
In charge of Expedition.

OCTOBER 14, 1901.

MOTION IN THE FAINT NEBULA SURROUNDING *NOVA PERSEI*.[1]

PHOTOGRAPHS of *Nova Persei* were obtained with the Crossley reflector by Messrs. H. K. Palmer and C. G. Dall between February 24 and March 29 inclusive, all of short exposure. It was planned to make a long exposure of the region about the *Nova*, but this was not done until the nights of November 7 and 8, as the telescope was used for spectroscopic work during the summer months. An exposure of $4^h\ 19^m$ was secured on the night of November 7, and 3^h on November 8, making a total of $7^h\ 19^m$. The exposure on the latter night was stopped

[1] *Lick Observatory, University of California, Bulletin* No. 10.

by the fog, which had been in the cañons and valleys, rising around the mountain top.

I had hoped to give an exposure of ten hours, but as the storm promised to be an extended one, I developed the plate on the following day. The seeing on the first night was excellent; on the second night it was only fair to start with, and toward the end became very bad at times. The resulting negative is not entirely satisfactory, the star images being somewhat elongated owing to the unstable mounting of the instrument, and blurred by the intervals of poor seeing. The large mirror has not been resilvered since it left England in 1895, so that considerable light is lost at this surface.

The plate used was a Seed 27 of a fresh emulsion. The negative shows but little fogging from the general illumination of the sky. Upon it are to be seen the nebula south of the *Nova* discovered by Professor Max Wolf[1] and most of the nebulosity shown on the photograph and drawing of Mr. Ritchey's negative.[2] The strongest nebulosity is very near to the *Nova*, adjoining it on the south and west. This mass is elongated in a general direction south of east and is nearly two minutes of arc in length. There are a number of very faint wisps to the south of the *Nova* for a distance of 6′, the outer ones being the stronger. These outer wisps are concave toward the *Nova*, on the arc of either a conic section, other than a circle, or of a spiral; but as only the outer end can be traced, the form of the curve remains undetermined. To the north of the *Nova*, and seeming to join it, there is a faint mass of nebulosity, while farther away in the same direction are traces of other masses, but they are too faint to make any structure certain. The image of *Nova* on the negative is 40″ in diameter.

A comparison of this negative with the reproduction from the photograph secured by Mr. Ritchey with the two-foot reflector of the Yerkes Observatory, on September 20, reveals some remarkable changes of position in the more pronounced condensations. Only four of these condensations are sufficiently defined to make determinations of position certain enough for purposes of comparison.

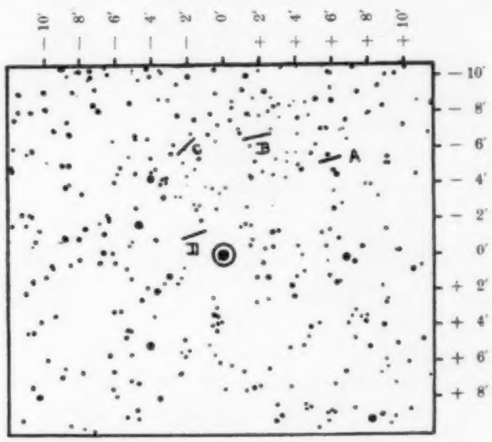
The accompanying diagram was made by taking a tracing of Mr. Ritchey's photographic reproduction (the fainter stars are not included), the centers of figure of the four condensations being indicated thereon by dots. The centers of figure of these same condensations were then

[1] *Astronomische Nachrichten*, No. 3736.

[2] ASTROPHYSICAL JOURNAL, 14, 167.

indicated in a similar way on the back of my negative and transferred to the tracing.

The four masses of nebulosity used are designated by the letters *A, B, C, D;* the positions which the centers of figure occupied on September 20, as shown in the reproduction from Mr. Ritchey's photograph, are occupied by the left-hand or northwest end of each of the short lines; the positions on November 7 to 8 are occupied by the right-hand or southeast ends of the lines.



The line drawn between these positions for each condensation indicates the direction and amount of motion in the interval of forty-eight days. Condensation *A* is much the best adapted for accurate measurement, from its greater strength and from its forked appearance; condensations *B* and *C* are not quite so good for measurement as *A*, but still are very determinate; but while condensation *D* is the brightest of all, it is large and so near the image of the *Nova* as to make its amount and direction of motion somewhat uncertain.

It will be seen that the displacements agree well, and amount to about $1\frac{1}{2}'$. The directions are not so consistent, and could perhaps be explained by irregular motions in the nebulous mass, by a general translation of the nebula in one direction, or by a spiral motion. It is certain, however, that the motion is not radial.

The amount of motion is almost incredible, being no less than at the rate of $11'$ per year. The greatest displacement (proper motion) in the stellar universe so far observed is less than $9''$ per annum.

Such an exceptional velocity as is here indicated leaves little doubt of the intimate connection of this nebulous matter with the *Nova* and its outburst.

It is perhaps too soon to say just what bearing the foregoing observations will have upon the explanation of the phenomena connected with new stars. It would seem, however, that such great velocities

pointed rather to a violent collision of some sort than to an outburst within a dark and comparatively cool body; but whether a collision of a solid body with another, or the passage of a solid body through a gaseous nebula or a swarm of meteorites, is uncertain.

It may be that in the outburst of *Nova Persei* we have seen the formation of a nebula, either planetary or spiral.

Professor Wolf's photographs were obtained on August 23, and a comparison with his nebula would be valuable; but neither reproductions of his photographs nor the accurate coördinates of the nebula have been published.

Mr. Joel Stebbins, Fellow in Astronomy, assisted in taking the photograph with the Crossley reflector.

C. D. PERRINE.

NOVEMBER 10, 1901.

THE AMHERST ECLIPSE EXPEDITION TO SINGKEP, 1901.

BY the generosity of Mr. Arthur Curtiss James, of New York, Amherst College was enabled to send out the sixth astronomical expedition in my charge.

Singkep (latitude 0° 30′ south, longitude 6^h 57^m east of Greenwich) was chosen because the chances of clear skies were not inferior to those of other available regions, as inferred from the very complete and carefully collected tables prepared by the Dutch Commission, under the direction of Major Muller and Dr. Figee.

Singkep is an island about fifteen miles across, and located off the east coast of Sumatra. It is tributary to the Dutch Residency of Riouw, and has frequent communication with Singapore, chiefly by means of the private steamer of the "Singkep Tin Maatschappij." This company and its fifteen mines occupy the island, and the officials of the company most courteously received the expedition as their guests.

The chief instruments were:

(*a*) The 12-inch Lyman speculum, freshly repolished by Brashear. (Focal length 15 feet, and diameter of Moon's image 1.8 inches.) This was mounted on an equatorial frame, with a long arm moved with great accuracy at one-half the rate of the Sun's diurnal arc-motion by means of a glycerine clock. The Sun's image therefore stood stationary upon the plates of the camera. This received the image directly without secondary refraction or reflection, and a little at one side of the

cylinder of rays incident upon the mirror. This amount was found by experiment to be well within that which would produce harmful distortion. The camera was further provided with the facilities for exposing wet collodion plates, in addition to the ordinary gelatine dry plates. Also it was fitted with a frame, holding a revolving mechanical occulter, of the improved type described elsewhere.[1] The unusual duration of totality permitted preparation for nearly fifty exposures.

(*b*) A double polariscope with a 2-inch lens of 28 inches focus, prepared by Dr. Wright of Yale University. Number of exposures, six.

(*c*) A 3½-inch Goerz lens of 33 inches focus, fitted to my automatic camera, previously used in Japan and Tripoli, and loaded with 352 Lovell backed plates, $2 \times 2\frac{1}{2}$ inches.

By the courtesy of Messrs. Bausch and Lomb, the Goerz Optical Company, and the Gundlach Optical Company, the expedition was provided with many other lenses of varied dimension and focal length. Mr. Leonard W. Pope, of Amherst College, and Mr. Rijbering, of the Singkep Tin Company also lent (1) a 6-inch silvered glass mirror, and (2) a Leviathan lens. All of these, fortunately, were pressed into service, through the kind interest and thoughtfulness of Mr. H. P. Krull, manager of the Singkep Tin Company, who provided me with the necessary artisans for constructing improvised cameras.

The uncertain character of the weather rendered it advisable to scatter the instruments as much as possible. Six auxiliary stations were accordingly established — three of them on the island of Singkep itself, at distances of one, five and twelve miles from the main station; one on Pulo Laya nearly thirty miles southeast of Singkep, by the courtesy of Admiral Dekkers, commanding the Dutch government steamer *Flamingo*; one on Pulo Lalang, about fourteen miles south of Singkep, and one on Lingga, about the same distance north of Singkep, by courtesy of the Sultan of Lingga, who considerately lent his steam yacht *Dalel* for transportation of instruments and observers.

At the last station only were photographs of the corona secured, by Baron van Boetzelaer, the Assistant Resident located there. Totality was not entirely cloudless with him, but he made over thirty exposures with the improvised camera which I sent him, twenty-eight of which are useful, and eleven very good. Unfortunately they are small, the lens used being the back lens of 22 inches focus, belonging

[1] *Monthly Notices Royal Astronomical Society*, **61**, 531, 1901.

to the "Leviathan" lent by Mr. Rijbering. These lenses were originally of French manufacture, and mounted in London for Messrs. Robinson & Company, of Singapore. It is an excellent achromatic giving a sharp focus. These plates used were Ilford Rapid, and they show the corona of 1901 as slightly if at all divergent in general form from that of 1900.

At all the other auxiliary stations, as well as at the main station in Singkep, clouds covered the corona, and no photographs could be taken. Nearly the whole forenoon had been radiantly clear, at all the stations. It was a dense cloud-bank slowly rolling over from the Sumatra coast, and rising higher and higher, that wrought the disaster.

Ten plates were exposed at the main station, prepared for the detection of any possible X ray effect in the coronal light, but no such action was discovered on developing them.

No observer at any of the stations saw the shadow-bands, except Madam van Boetzelaer, at Lingga, who reported them as having an oscillatory motion during a portion of totality. At my suggestion many observers in Singapore also looked for shadow-bands, as it is quite possible the bands should be visible a little outside the belt of totality, just as they can be seen at stations within the belt, but during the narrow crescent phase just before and after totality. Although the skies were perfectly clear at Singapore, however, no shadow-bands were seen there.

Meteorological observations of the type requested by Mr. A. Lawrence Rotch, of Blue Hill, were made on my request by Dr. Leicester of the hospital at Singapore, and at Singkep by Mr. H. Loriaux, representative of the Singkep Tin Company in Riouw.

Four observers were prepared with occulting disks suitably mounted to obscure the bright inner corona and enable them to catch the outer streamers, and six others to sketch the entire corona; but clouds precluded result.

A few interesting effects of totality upon the animal world were noted.

About an hour after contact III the sky cleared, and remained so till sunset; so that I secured contact IV.

I built anew a type of mechanical commutator for operating the photographic instruments automatically. Though simple in form and very inexpensive, it proved very competent for the purpose intended, and I have made it the subject of a separate paper elsewhere.

Also I have described the elaborate arrangements for utilizing the

telegraph, to enable Mr. Maunder at Mauritius to dispatch an immediate message regarding his observations to the astronomers at Padang where totality came on an hour and a half later. The telegraph lines Mauritius, Zanzibar, Aden, Bombay, Madras, Penang, Padang were held open at the exact time requested, and expectantly for the Mauritius message—which might easily have gone through in ten to fifteen minutes. For the completeness of these arrangements the thanks of astronomers are due Mr. W. Grigor Taylor, General Manager Eastern Extension Telegraph Company at Singapore, who, at once on my suggestion, took the matter in hand with keen interest and genuine enthusiasm. The expected message was to convey some knowledge of—(*a*) the position of any comet or intramercurial planet seen, (*b*) the general form of the corona, (*c*) the abnormal brightness or faintness of the characteristic coronal line, (*d*) the general nature of the Mauritius results.

The message was actually dispatched last year, from Mr. Douglas's station in Georgia, to my own in Tripoli, in the very brief interval of twelve minutes; and the possibility of transmitting a similar message between remote stations this year in practically the same interval, have proven beyond a doubt the availability of the telegraph as an adjunct in eclipse research. There will never perhaps be time for the development of photographs; but certain optical observations are always possible, and worth the trouble of instant communication. Should the eclipse of 1905 fall total in Malta or Alexandria, the cable can again be called into service to notify observers there as to results secured in Spain.

Through the interest and assistance of Mr. van Dijk, of the Singkep Tin Company, I was enabled to carry out some preliminary experiments in the direction of securing eclipse observations at sea. These were favored by the fact that the ocean to the east of Singkep was nearly always motionless, and that the sky over it was cloudless at the eclipse hour during many more days than from any part of Singkep itself. Our experiments were confined to the construction of a triangular raft, the floating power being derived from six large oil drums. Had not the sea become too rough the night before to permit the safe use of so frail a craft, the expedition might easily have secured valuable photographs of the corona at sea, for about ten miles to the east the sky was unclouded during totality. I hope to have an opportunity to experiment with this method further, before the eclipse of 1904, which

is almost wholly upon the waters of the Pacific. Our experiments at Singkep quite satisfied me that, unless the ocean is very rough, it is an unnecessary assumption that eclipse observations of value are wholly precluded at sea.

DAVID P. TODD.

THE SPECTRUM OF *NOVA PERSEI.*

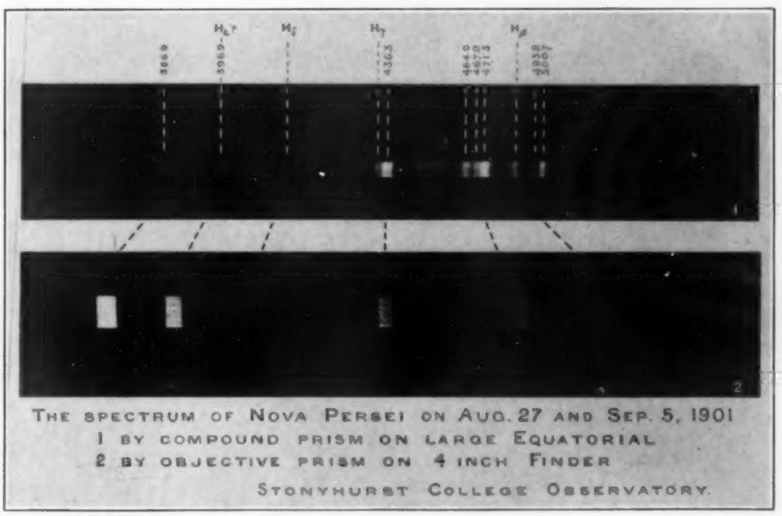
To the Editor of the ASTROPHYSICAL JOURNAL.

SIR: Please accept enclosed photographs of the spectrum of *Nova Persei.* You will see that the likeness to the Nebula 3918, mentioned by Professor Pickering in *A. N.* 3735, has improved as regards the lines 5007 and 4364. But is not the likeness spoiled by the great width of the fading hydrogen lines, and by the strong lines 3869, 3969, 4640, and 4713? And again, the *structure* of the three lines 3869, 3969, and 4364 is new. These lines are marked in the same manner, quite symmetrically, by four brighter lines crossing each, at the same spectral intervals. They are just discernible in the print, and are very clear on the negatives. They are stronger and clearer in the more refrangible lines in seven photographs taken between August 27 and October 6. They are distinct enough in the line 4364 on August 27, September 5, and October 6, but are lost on intermediate plates by want of light for the objective prism and by want of definition by the compound prism.

In my notes on the spectrum in March, which you kindly published in the ASTROPHYSICAL JOURNAL **13**, 4, I referred to a periodic change in the spectrum coinciding with the light changes. Since then I have been able to compare all my photographs of the spectrum with the magnitudes of the star as measured at the Radcliffe Observatory, Oxford; and it appears from these that the then new spectrum was connected, not with the minimum phase of the star's light curve, but with the absolute magnitude 4.57 of the Radcliffe measures. The older spectrum appeared always when the magnitude was greater, and the new spectrum when the magnitude was less than this figure; and the spectrum on April 9, when the magnitude was 4.57, had been already noted as partly of the old form and partly of the new form.[1] On this date the star was losing light, and the new blue band 4640 (oxygen triplet?) was beginning to form. On April 11 the new spectrum was complete; but the magnitude of the star was not obtained at the Radcliffe Observatory. On April 12, at magnitude 4.67, the

[1] *M. N.*, May 1901, note 4, on the spectrum of *Nova Persei.*

PLATE XXIII.



SPECTRUM OF *NOVA PERSEI.*

new spectrum was also complete, the lines 3869 and 4364 being fully formed, and it was also complete on March 28, at magnitude 4.61. It seems, therefore, right to say that the lines 3869 and 4364 came into being at a temperature indicated by the light-magnitude 4.6.

But the line 3969 (at the position of $H\epsilon$) probably belongs to a lower temperature. It was in full strength on April 11, being then much stronger than $H\delta$; but we have not the measured magnitude for this, only my own note that the star was brighter on the 12th, when the magnitude was 4.67, and then the line was not in full form. It was again stronger than $H\delta$ on the 16th, at magnitude 5.32; it was not so on a later date, April 23, at magnitude 4.36, and it was not so on an earlier date, March 22, at magnitude 5.20. In this way the appearance of $\lambda 3969$, whether it be an abnormal state of hydrogen radiation or a new superposition, is connected with the temperature represented by the star's magnitude between 5.2 and 5.3.

If, therefore, temperature is the real cause of the intensity and structure of the star's light, there is a way of obtaining an absolute measure of the temperature of *Nova Persei* through its spectrum. For the temperature represented by the magnitude at the appearance of any one of these lines is the higher limit of the range of temperature within which the particular radiation is possible. It remains therefore to discover the true origin of any one of these three lines, and to find the higher temperature at which the line vanishes. It may never be possible to measure this temperature; but it would be something to know that a stellar temperature was an artificial possibility.

Yours faithfully,

WALTER SIDGREAVES.

STONYHURST COLLEGE OBSERVATORY,
October 17, 1901.

SPECTRUM OF LIGHTNING.[1]

PHOTOGRAPHS of the spectrum of lightning were obtained on July 18 and 21, 1901, by Mr. J. H. Freese, under the direction of Mr. Edward S. King. The eight-inch Draper telescope was used with an objective prism. The telescope was directed to the portion of the sky in which the lightning was particularly bright, and when the observer thought that he had obtained an image, the plate was changed. Even then many of the plates were badly fogged. A number of photographs

[1] *Harvard College Observatory Circular* No. 62.

were taken in this way, and showed the curious fact that the spectrum of lightning is not always the same. One flash, on July 18, showed three bright bands, while another taken on the same evening showed ten bright lines, and closely resembled one taken on July 21. The latter is shown in Plate XXIV. To increase the contrast of the original negative, a double contact print was made from it with slow plates, and is reproduced in the plate on the original scale. The brighter portion of a second flash, clearly seen in the original negative, also appears in the print. Measures, each consisting of three settings, were made of three portions of the principal spectrum, and the means of the results are given in Table I. The original negative was an isochromatic plate. The successive columns give the hydrogen lines with which certain of the lines are assumed to be identical, the mean wave-length and intensity of the lines in the spectrum of lightning, and the wave-length and intensity of the principal lines in the spectrum of *Nova Persei*, No. 2, on March 23, 1901.

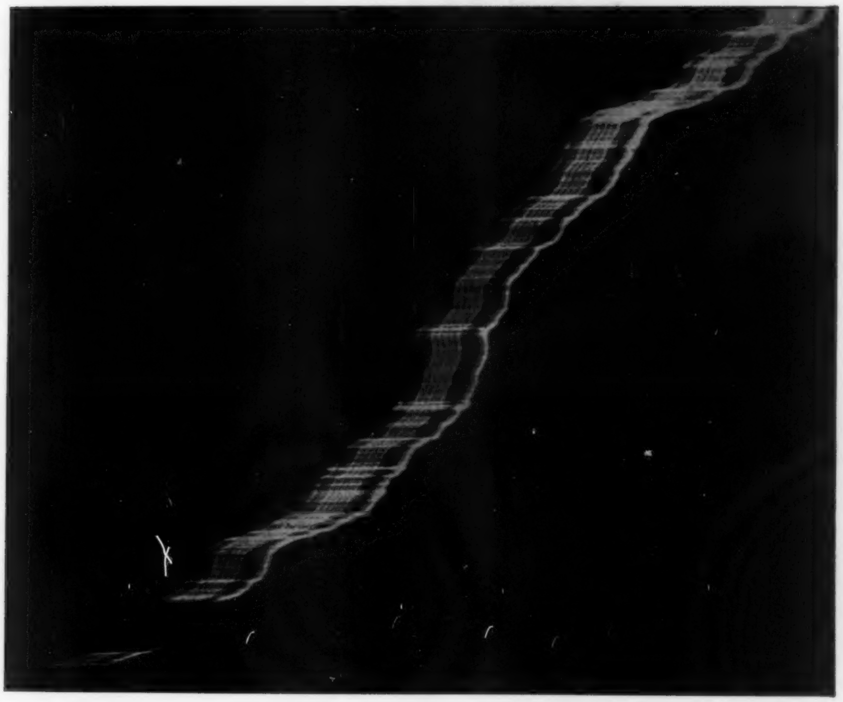
TABLE I.

SPECTRA OF LIGHTNING AND *NOVA PERSEI*.

Hyd.	W.-L.	Int.	W.-L.	Int.	Hyd.	W.-L.	Int.	W.-L.	Int.
Hη	....	..	3836	4	*Hγ*	4341	5	4341	10
Hζ	3881	10	3889	5		4441	?	4468	4
	3956	2	3970	7		4519	1	4573	3
Hε	3998	3				4643	8	4646	6
	4046	2	4030	2		4754	1	....	..
Hδ	4102	8	4102	8	*Hβ*	4861	5	4862	10
	4147	4	4149	1		4940	?	4925	1
	4187	?	....	..		5022	2	5015	3
	4222	5	R	2		5173	1	5171	3
	4263	1	....	..		5595	30	R	20

The first line in the spectrum of lightning is a broad, bright band, extending from wave-length 3830 to 3930, and is perhaps identical with the nebular line 3875. The line 4222 appears as a broad band in the *Nova*. The last band is very broad or perhaps a continuous spectrum extending in both objects from about wave-length 5300 to 6000. The lines in the two spectra appear to resemble each other closely both in position and in intensity. On September 15, 1901, a photograph was obtained with the eleven-inch Draper telescope, showing nearly thirty bright lines. Some of these show a curious doubling,

PLATE XXIV.



SPECTRUM OF LIGHTNING.

the separation varying in different portions of the flash. Apparently, this is due to another flash, in whose spectrum only a portion of the lines appear.

EDWARD C. PICKERING.

NOVEMBER 16, 1901.

MOTION IN THE LINE OF SIGHT.

The following letter, which has an important bearing on the history of astrophysics, is reprinted from the *Observatory* for December 1901:

GENTLEMEN: It is always with extreme reluctance that I write on any personal matter. In Sir David Gill's recent address at the Cape, printed in your last number, the statement appears that about 1865 my "attention was directed by Clerk Maxwell to this possibility of the new astronomy." (Determination of motion in the line of sight.)

So far from this having been the case, the method suggested itself to me directly from Doppler's work, sometime in 1862–3. Among the first words of my paper on the subject in *Phil. Trans.*, 1868, are the following: "We were fully aware at the time (1863) . . . . that these comparisons might serve to tell us something of the motions of the stars relatively to our system." (P. 529.)

The inclusion of Clerk Maxwell's letter in my paper came about in this way. Wishing to make the historical introduction to my paper as complete as possible I asked my friend, Clerk Maxwell, in 1867, to give me an account of some experiments which I had heard he had been making to detect the influence of motion on the refrangibility of light. His letter, which I did not receive until June 1867, appeared to me to be of so much interest that instead of making extracts from it I requested his permission to print it in full in my paper. Clerk Maxwell's reply, which I quote from a letter dated March 23, 1868, shows clearly that my work had been independent, and not undertaken in consequence of a suggession of his. His words are: "If it appears to you that what I sent you last summer would answer as part of your paper, it would be very agreeable to me to have it placed beside your work, so that if it should contain anything not applicable to your methods, or to which your methods are not applicable, the difference may be seen to be the effect of independent working, and not of opposition or criticism." Yours faithfully,

WILLIAM HUGGINS.

UPPER TULSE HILL,
November 9, 1901.

Reviews

Recherches Expérimentales sur les Spectres d' Étincelles. Par G. A. Hemsalech. Pp. 138. Paris: Hermann, 1901.

This volume deals with a subject which, at the present moment, is of especial interest to all spectroscopists, namely, the constitution of the electric spark. The earlier part of the book contains a clear and orderly account of all the more important work hitherto done along this line, while the later part of the volume gives a number of new and valuable results recently obtained by Mr. Hemsalech in the research laboratory of the Sorbonne, and offered by him as a thesis for the degree of Doctor in Science. The starting point of this latter work is the series of discoveries made jointly by Schuster and Hemsalech, and published in the *Phil. Trans.* **193**, 189–213, 1899, and in *Proc. Roy. Soc.*, **64**, 335, 1899.

These results may be briefly summarized as follows:

1. The ordinary Leyden jar discharge may be considered as made up of three parts or phases, namely: (1) an initial discharge, which opens up a luminous path by breaking down the air insulation and producing an air spectrum; (2) an "aureole" of metallic vapor filling the region between the electrodes, and remaining luminous long after the initial discharge is over; (3) a series of oscillatory discharges taking place in this atmosphere of metallic vapor as a medium, and giving rise to the characteristic metallic spectra.

2. The introduction of self-induction without iron serves to intensify the metallic spectra, and to weaken the air spectrum. By this means the air lines may be practically eliminated.

3. The introduction of resistance into the discharge circuit renders the discharge intermittent, deadbeat, and feeble.

4. All metallic lines are not affected in the same way by the introduction of self-induction — some are intensified, while others are weakened.

Starting upon this foundation, Hemsalech has added the following facts:

1. Metallic lines which disappear as the self-induction of the circuit

is increased do so by first becoming "short"—in Lockyer's sense—and then "shorter," and finally mere luminous points about the electrodes.

2. The effect of self-induction, affecting different lines in different ways, gives a basis for the division of the lines in spark spectra into three groups. The first of these groups includes all those lines which diminish rapidly as self-induction is increased. This class includes air lines and the "short" metallic lines which appear in the spark only. As typical lines the following are mentioned: *Mg* 4481.4, *Pb* 4244.9, and *Pb* 4386.6. The second group includes all lines which diminish slowly and gradually with increase of self-induction. Into this class fall those lines which are strong, and which are common to both spark and arc; in general they are reversed or nebulous. As types the *Mg* triplets at λ 5183 and at λ 3838 are cited. Into the third group he puts those lines which at first diminish in intensity, reach a minimum, afterwards increase considerably, and, having reached a maximum, again diminish. "Most of the lines in the spectra of iron and cobalt" are cited as typical of this class. Practically all of the lines in the series of Kayser and Runge belong in the second group.

3. Concerning temperatures of spark and arc, Mr. Hemsalech (p. 132) concludes that the first of the groups just mentioned contains the high temperature lines; that the second group includes those lines which are produced at the temperature of the arc and persist at a temperature much lower than that of the arc; and that the third group of lines is due to a temperature which is about that of the arc.

4. Concerning the fourteen different metals examined, namely: *Fe, Mn, Co, Ni, Cd, Zn, Mg, Al, Sb, Sn, Bi, Pb, Cu, Ag*, Mr. Hemsalech finds that they may be divided into two groups, according as most of the lines are increased or decreased in intensity, when the self-induction in the discharge circuit is increased. One of these groups includes iron and three of its related elements, *Mn, Co, Ni;* the other group contains all the rest of the fourteen elements mentioned above.

5. For each of these fourteen elements is given a table of the principal wave-lengths, accompanied by intensities in the ordinary spark, in the oscillating spark and in the arc.

H. C.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

The editors do not hold themselves responsible for opinions expressed by contributors.

The ASTROPHYSICAL JOURNAL is published monthly except in February and August. The annual subscription price for the United States, Canada, and Mexico is $4.00; for other countries in the Postal Union it is 18 shillings, 6 pence. Correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago, University Press Division, Chicago, Ill.*

Wm. Wesley & Sons, 28 Essex St., Strand, London, are sole European agents, and to them all European subscriptions should be addressed.

All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.*

INDEX TO VOLUME XIV.

SUBJECTS.

For titles of Reviews see Table of Contents.

INDEX TO VOLUME XIV.

AUTHORS.

tri

VOLUME XIV NUMBER 5

THE ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

DECEMBER, 1901

CHICAGO
The University of Chicago Press
WILLIAM WESLEY & SON, 28 Essex St., Strand, London
Sole Foreign Agents

SUBSCRIPTION, FOUR DOLLARS SINGLE NUMBERS, FIFTY CENTS


APPLES MAKE
CIDER
BUT
PEARS MAKE
SOAP

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOL. XIV DECEMBER, 1901 NO. 5

The ASTROPHYSICAL JOURNAL is published monthly except in February and August. Annual subscription, $4.00; foreign, $4.50. *Wm. Wesley & Son, 28 Essex Street, Strand, London*, are sole European agents and to them all European subscriptions should be addressed. The English price is 18 shillings 6 pence. All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.* All **correspondence** relating to subscriptions and advertisements should be addressed to *The University of Chicago Press, Chicago, Ill.* All **remittances** should be made payable to the order of *The University of Chicago.*

SPECIAL TO FOREIGN SUBSCRIBERS.—The attention of foreign subscribers is called to our rate of $4.50, necessitated by the addition of extra postage. In the future the price to be remitted to our European agents, *Wm. Wesley & Son*, should be 18s. 6d. per year.

[Entered at the Post-Office at Chicago, Ill., as second-class mail matter.]

Blennerhassett

A Thrilling Romance

OF AN INTENSELY DRAMATIC FLAVOR

"Nearly every chapter is full of incident and action and there are dramatic touches which display fine literary skill. The author's canvas is crowded with interesting personages of importance.

"Mr. Pidgin has greatly increased our respect for Burr, and has set us thinking.

"If the historical novel is to remain a fixed institution, we shall be happy to see it take the form of works similar to Blennerhassett."—*Richmond Dispatch, September 15, 1901.*

12 Full-page Illustrations. Price $1.50

By CHARLES FELTON PIDGIN, author of

Quincy Adams Sawyer

"The best New England story ever written."

Now Nearing its Two-hundredth Thousand

AT ALL BOOKSELLERS,

In preparation MISS PETTICOATS

If you have not read "Home Thoughts" you have missed the literary treat of the year. A notable critic compares its style to that of Washington Irving and George Wm. Curtis. It isn't a continuous story, you can read a chapter at a time. Exceedingly interesting in every line, it touches deeply that which is nearest and dearest to us all. The relations of husband and wife, parent and child, and the broad field of home life give the chief themes. No recent book is so valuable as a help to right thinking and right living as "Home Thoughts."

FOURTH EDITION IN PRESS. CLOTH, $1.50

THE BEST GIFT BOOK IS

Home Thoughts

By "C"

DR. A. H. BRADFORD says: "One of the sanest, soundest, and most helpful books of the kind that I ever read."

Sold by All Booksellers Sent, Postpaid, by

A. S. BARNES & CO., 156 Fifth Av., New York

OUR CATALOGUE FREE TO ANY ADDRESS

Two Grand Winter Cruises

TO THE

WEST INDIES

By the Specially Constructed, Magnificent, New, Twin-Screw Cruising Yacht

PRINZESSIN VICTORIA LUISE

OF THE

HAMBURG-AMERICAN LINE

LEAVING NEW YORK Jan. 4th, 1902; Feb. 8th, 1902

These cruises offer unparalleled opportunities to visit—under the most favorable auspices, and upon a specially designed and perfectly equipped steamship—the new possessions of the U. S. in the WEST INDIES, the neighboring islands, the SPANISH MAIN, and MEXICO.

ITINERARY

FIRST CRUISE from New York to San Juan (Porto Rico); **St. Thomas; St. Pierre** (Martinique); **Port of Spain and La Brea** (Trinidad); **La Guayra; Puerto Cabello** (Venezuela); **Curacao; Kingston** (Jamaica); **Santiago and Havana** (Cuba); **Charleston, S. C., and return to New York. A total distance of 5,320 miles, occupying 30 days. WITH SIDE TRIPS to CARACAS and VALENCIA, VENEZUELA.**

SECOND CRUISE from New York to San Juan (Porto Rico); **Domingo City** (Santo Domingo); **Kingston** (Jamaica); **Santiago de Cuba; Vera Cruz** (Mexico); **Havana** (Cuba); **Charleston, S. C., and return to New York. A total distance of 5,510 miles, occupying 28 days. WITH SIDE TRIP TO MEXICO CITY.**

For further information, rates, etc., apply to Dept. 17 of the

HAMBURG-AMERICAN LINE

35-37 Broadway, New York
1229 Walnut St., Philadelphia
159 Randolph St., Chicago
70 State St., Boston
106 N. Broadway, St. Louis
401 California St., San Francisco

Pens-Pens

EASE IN WRITING
FALCON No. 048

Other Leading Numbers. 14. 130. 313. 442.

ESTABLISHED 1860

ESTERBROOK STEEL PEN CO.
26 JOHN ST. NEW YORK.

FOR SALE BY ALL STATIONERS.

The
Remington Typewriter

has the

Lightest Touch

that saves labor; and does the quickest work—that saves time. Time and labor saved by the REMINGTON

Wyckoff, Seamans & Benedict, New York.

THE PROGRESS OF TIME

Is Marked by Great Improvements in all Lines of Industry and Manufacture.

Dixon's American Graphite Pencils

Are a 20th Century Product that leads the World in its Field. Ask for and insist on Dixon's and have the best.

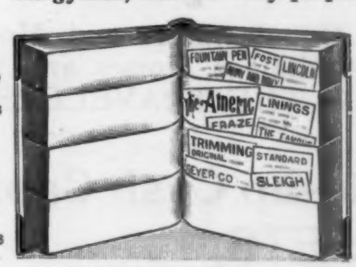
When not at dealers, mention this publication and send 16 cents for samples worth double.

JOSEPH DIXON CRUCIBLE CO., Jersey City, N.J.

IT'S A WONDER

For Bankers, Lawyers, Doctors, Clergymen, and all busy people

All Scrap Books 9½ x 11¾ inches



An excellent Christmas Gift

Don't Lay Clippings and Other Papers on your desk. You'll lose them. Tuck them in the pockets of a **Perfect Scrap Book** and keep them ready for reference. Indispensable to all intellectual people. For **One Dollar** we will send you a 24-page (72 pockets) **Perfect Scrap Book** in substantial half linen binding. Library edition 204 pockets, half Morocco, $3.00; College edition, 120 pockets, half Morocco, $2.00. A trial size portfolio (fine for private correspondence) 12 pockets for 20c. all postpaid on receipt of price.

Circular free on request. Leading Stationers.

THE PERFECT SCRAP BOOK CO.
Dept. V. 150 Nassau St., New York City

We've a Wallet size handy for the pocket. Sent postpaid for 25 cents